2011 Monitoring Final Report for King County BMP Effectiveness Monitoring Under S8.F of the NPDES Phase 1 Municipal Permit WAR04-4501 (Issued February 2007)

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King County

Department of Natural Resources and Parks
Water and Land Resources Division
Science Section
King Street Center, KSC-NR-0600
201 South Jackson Street, Suite 600
Seattle, WA 98104
dnr.metrokc.gov/wlr

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Prepared by
King County Department of Natural Resources and Parks
Water and Land Resource Division
and
Cardno TEC

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Submitted by:

King County Water and Land Resources Division
Department of Natural Resources and Parks

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Executive Summary

This document serves as King County's final report on Special Condition 8.F. Stormwater Treatment and Hydrologic Management Best Management Practice (BMP) Evaluation of the Phase I Municipal Stormwater Permit. This report documents the results and analysis of the BMP monitoring conducted between October 2009 and December 2011. The BMP monitoring is intended to evaluate the effectiveness and operation and maintenance requirements of selected stormwater treatment and hydrologic management BMPs.

The facilities monitored for this section of the Municipal Stormwater Permit include two large sand filters each of which are preceded by a pre-settling detention basin. These stormwater treatment BMP facilities are located in the City of Sammamish, and serve a multi-family apartment development at 4425 Issaquah Pine Lake Rd SE. Each sand filter and detention basin treats runoff from roughly half of the developed area.

Water quality and flow data have been collected in a way that the pollutant removal efficiencies of each facility can be calculated to determine if and how well these facilities are functioning. Water quality, sediment quality, and flow data have been collected from six locations for this study and these are:

• Inflow to both pre-settling detention basins;

• Outflow from both pre-settling detention basins (which is also Inflow to each sand filter); and,

• Outflow from each sand filter.

Methods

Sampling design for evaluation of the BMPs was based on <u>Draft Modification: Evaluating Stormwater Treatment Technologies with Long Detention Times – Technology Assessment Protocol – Ecology</u> (Ecology, 2008b) or TAPE. Automated samplers with flow meters were used to collect flow-weight composite samples on randomly selected days. Samples were collected over a 24-hour period. Sediments were also collected at each site. A minimum of 12 samples were to be collected at each sampling location with a statistical goal of 90 to 95% confidence with 75 to 80% power for Total Suspended Solids (TSS), total and ortho phosphorus, pH, hardness, and total and dissolved copper and zinc. A maximum of 35 samples were required if the statistical goals could not be met.

For this study, a total of 137 water quality samples were collected. However, because flow through the pre-settling basins and sand filters was apparently slower than the hydraulic monitoring equipment can accurately measure, and because flow through the system occurred over a period of time longer than 24 hours, field crews had difficulty predicting flows and collecting samples according to one of the TAPE guidelines that called for sampling at least 75% of the flow volume during the 24 hour sampling period.

Since the collected data met all other quality goals, a statistical assessment of the data was conducted to determine the usability of the data. Data were separated according to whether they met the TAPE sample collection guideline for collecting 75% of the 24 hour flow or not. The statistical analysis showed that there were no significant differences at the 95% confidence interval between the data that met the 75% flow for the 24-hour period guideline and the samples that did not meet this guideline. Therefore, these data were determined to be usable for BMP efficiency calculations.

Results

Based on TAPE guidelines, the treatment performance goals for basic treatment is 80 percent removal for TSS concentrations where influent concentrations fall between 100 to 200 mg/L. For influent concentrations less than 100 mg/L, the effluent goal is less than 20 mg/L.

For the pre-settling basins, concentration based pollutant removal efficiency for TSS was 48 percent. All influent concentrations were less than 100 mg/L. While the Boulder Creek Pre-Settling Detention Basins do meet the TAPE treatment performance goals with a mean effluent concentration of 8.99 mg/L and a median effluent concentration of 4.2 mg/L, the mean influent concentration was already below the effluent TSS goal of 20 mg/L.

For the sand filters, concentration based pollutant removal efficiency was 91 percent. Again, the Boulder Creek large sand filter results do meet the TAPE goals with a mean effluent concentration of 0.81 mg/L and a median effluent concentration of 0.5 mg/L. However, the mean influent concentration was already well below the effluent TSS goal of 20 mg/L. In addition, 72 percent of the TSS effluent concentrations were below the reporting limit, and therefore the 91 percent removal efficiency should be considered an estimate.

TAPE guidelines set a goal for phosphorus treatment at 50 percent removal for influent total phosphorus concentrations between 0.1 mg/L and 0.5 mg/L. For influent concentrations greater than 0.5 mg/L a higher percent removal goal may be appropriate.

For the pre-settling detention basin BMP, influent total phosphorus concentrations ranged from 0.0186 mg/L to 0.244 mg/L, with 82.5 percent of influent samples falling below the concentration range stated in TAPE. The mean influent concentration was 0.0572 mg/L while the mean effluent concentration was 0.06579. This resulted in a concentration based pollutant removal efficiency of -15 percent. These results do not appear to meet the TAPE treatment performance goals, however the detention pond and detention vault BMPs are not designed for phosphorus removal.

For the large sand filter BMP, the influent total phosphorus concentrations ranged from 0.0148 mg/L to 0.383 mg/L, with 75 percent of influent samples falling below the concentration range needed to conform to TAPE. The mean influent concentration was 0.066 mg/L while the mean effluent concentration was 0.023. This resulted in a concentration based pollutant removal efficiency for total phosphorus of 65 percent. This does meet the TAPE treatment performance goals, however due to the low influent concentrations it is uncertain if these data would meet the TAPE goals.

Enhanced treatment goals for TAPE state data collected for an enhanced BMP should demonstrate significantly higher removal rates for dissolved metals than basic treatment BMPs. In addition to the removal goals, TAPE criteria states influent dissolved copper concentrations must be in the range of 0.003 to 0.02 mg/L (3 to 20 μg/L) and influent dissolved zinc concentrations must be in the range 0.02 to 0.3 mg/L (20 to 300 μg/L).

For the pre-settling detention basin BMP, influent dissolved copper concentrations ranged from 0.00048 mg/L to 0.00503 mg/L, with 70 percent of the 40 samples falling below the influent concentration range required by TAPE. The mean influent dissolved copper concentration was

0.00215 mg/L and the mean effluent concentration was 0.00153 mg/L, resulting in concentration based pollutant removal efficiency for dissolved copper of 29 percent. Influent dissolved zinc concentrations ranged from 0.00383 mg/L to 0.022 mg/L, with 97.5 percent of the 40 samples falling below the influent concentration range required by TAPE. The mean effluent dissolved zinc concentration was 0.00552, resulting in a 33 percent reduction in dissolved zinc. Due to the low influent concentrations it is unlikely these data would meet the TAPE goals, however the detention pond and detention vault BMPs are not designed for enhanced treatment.

For the large sand filter BMP, 89 percent of the 53 samples fell below the influent dissolved copper concentration range required by TAPE. The mean influent dissolved copper concentration was 0.00154 mg/L and the mean effluent concentration 0.00224 mg/L, resulting in a -46 percent reduction in dissolved copper. For dissolved zinc samples, 98.2 percent of the concentrations fell below the range required by TAPE. The mean influent dissolved zinc concentration was 0.00552 mg/L and the mean effluent concentration was 0.00234 mg/L, resulting in a 58 percent reduction in dissolved zinc. As with the detention basin BMP, due to the low influent concentrations it is unlikely these data would meet the TAPE goals.

In summary, because of low influent concentrations of total phosphorus (there is no TAPE goal for othophosphorus), and total and dissolved copper and zinc to the pre-settling basins and the sand filters, removal efficiencies cannot be calculated according to TAPE goals.

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1.0. INTRODUCTION

The Washington State Phase I Municipal Stormwater Permit (Phase I Permit) applies to all entities in Washington State required to have permit coverage under current (Phase I) U.S. Environmental Protection Agency (EPA) and Washington State Department of Ecology (Ecology) stormwater regulations. This includes cities and unincorporated portions of counties whose populations exceed 100,000. The Phase I Permit includes requirements to conduct stormwater-related monitoring in Special Condition 8 (S8). The required monitoring program detailed in S8 includes three components:

- S8.D Stormwater Monitoring
- S8.E Targeted Stormwater Management Program Effectiveness Monitoring
- S8.F Stormwater Treatment and Hydrologic Management Best Management Practice (BMP) Evaluation Monitoring

Reporting for all three monitoring components is required as part of Special Condition S8.H and S9. These sections require Permittees to complete an annual report for each component, to be submitted no later than March 31, detailing monitoring that occurred during the previous water year. A water year starts on October 1 and ends on September 30 of the following year.

This document serves as King County's (County) final BMP report, and documents the results and analysis of the BMP monitoring conducted under S8.F of the Phase I Permit between October 2009 and December 2011. The BMP monitoring is intended to evaluate the effectiveness and operation and maintenance requirements of selected stormwater treatment and hydrologic management BMPs.

The Phase I Permit instructs permittees to use appropriate sections of Ecology's Guidance for Evaluating Stormwater Treatment Technologies – Technology Assessment Protocol – Ecology (TAPE) (Ecology, 2008a) for the BMP evaluation monitoring. The BMPs that King County selected for monitoring (detailed in Section 2.2) are considered long-detention BMPs, therefore monitoring was conducted following Ecology's TAPE Modification: Evaluating Stormwater Treatment Technologies with Long Detention Times (Ecology, 2008b).

The permit requires that either data meet the statistical goal of determining effluent concentrations and mean percent removals for each BMP type with 90 to 95 percent confidence and 75 to 80 percent power, or a maximum of 35 influent and effluent sample be collected for each permit required parameter. As detailed in Section 5.0 the permit goals were met and therefore, as outlined in Ecology's Stormwater Monitoring Report Guidance (Ecology, 2010), this document serves as the final BMP report.

2.0. SUMMARY OF THE PURPOSE, DESIGN, AND METHODS OF THE MONITORING PROGRAM

2.1 Overview

Stormwater monitoring, to fulfill requirements of the Phase I Permit (per Permit §S8.F), was performed by King County in accordance with their project Quality Assurance Project Plan (QAPP) entitled Quality Assurance Project Plan for King County BMP Effectiveness Monitoring Conducted Under the Phase 1 Municipal Stormwater Permit WAR04-4501 (Issued February 2007) (King County, 2010). This QAPP was issued in February 2007, approved by Ecology on April 27, 2009, and updated in November 2010. The updated QAPP is included as Appendix A.

The permit requires each Permittee to monitor at least two treatment BMPs, at no less than two sites per BMP. King County selected to evaluate two Pre-Settling Detention Basins and two Large Sand Filters, as described below.

2.2 Description of Treatment BMPs

The stormwater treatment BMP facilities are located in the City of Sammamish, and serve a multi-family apartment development at 4425 Issaquah Pine Lake Rd SE. There are two BMP facilities located on the site, as shown in Figure 1, Boulder Creek Upper BMP and Boulder Creek Lower BMP. Each facility treats runoff from roughly half of the developed area. Both facilities include a large sand filter preceded by a pre-settling detention basin. Plan and cross sectional drawings of each BMP are included in Appendix B.

2.2.1 Pre-settling Detention Basin

Pre-settling detention is provided immediately upstream of each of the large sand filters. The Boulder Creek Upper BMP pre-settling basin is a detention pond while the Boulder Creek Lower BMP pre-settling basin is a detention vault. Both pre-settling basins were sized as Level Two Flow Control facilities per the 1998 King County Surface Water Design Manual (KCSWDM) using the King County Runoff Time Series (KCRTS) program. Level 2 Flow Control Facilities are designed to maintain the "durations of high flows at their predevelopment levels for all flows greater than one-half of the 2-year peak flow up to the 50-year peak flow" (King County, 2009).

2.2.1.1 Boulder Creek Upper Pre-Settling Detention Basin (Detention Pond)

A detention pond is an open basin that operates by providing temporary storage for stormwater runoff. It is constructed with an outlet control structure that is designed to detain stormwater runoff to allow for sediment and associated pollutants to settle. The function of a detention pond BMP is to provide flow control and basic runoff treatment for total suspended solids (TSS).

Figure 1. Drainage area for and location of pre-settling basins and large sand filters

The detention pond at the Boulder Creek facility provides 227,443 cubic feet of storage. The pond is lined, and therefore does not show any significant water gain or loss. Stormwater flows into the pond through an 18-inch pipe. A 2-foot gabion wall runs through the pond to direct and slow down the flow. Flows out of the pond pass through a flow restriction device before entering the 12-inch outlet pipe and flowing into the large sand filter. The pond is built with an emergency overflow structure that restricts pond depth to 10.5-feet. If the water level in the pond exceeds 10.5-feet the overflow enters a 12-inch pipe which bypasses the flow restriction device and the large sand filter.

2.2.1.2 Boulder Creek Lower Pre-Settling Detention Basin (Detention Vault)

A detention vault is generally a box-shaped BMP constructed of reinforced concrete that serves as an underground storage facility. Similar to detention ponds, detention vaults are typically constructed with an outlet control structure which slows storm flow to allow for sediment and associated pollutants to settle. Detention vaults provide flow control and basic runoff treatment for total suspended solids (TSS).

The detention vault at the Boulder Creek facility measures 13-feet tall by 26-feet wide by 126-feet long internally. A concrete wall bisects the vault to slow down the flow. A 15-inch pipe through the base of the wall provides a pass through for flow, which then passes through a flow restriction device before entering the 12-inch outlet pipe and flowing into the large sand filter. The vault is built with an emergency overflow structure that restricts water depth within the vault to 12.5-feet, which results in the vault providing 40,950 cubic feet of storage.

2.2.2 Large Sand Filter

The sand filter is described in the 1998 KCSWDM as media filtration facility which uses a sand layer as the media. Flow is filtered as it passes vertically through the sand and pollutants either adhere to the sand or are trapped in the interstitial spaces between the sand grains. The large sand filters remove pollutants mostly via filtration, though biological treatment may occur after time if soil bacteria grow in the sand bed (WSDOT, 2008). According to the Sensitive Lake Protection Menu of the 1996 Draft Surface Water Design Manual, the large sand filters are designed to remove 50 percent of the total phosphorus. In addition to phosphorus, the large sand filters are designed for basic (TSS) and enhanced (dissolved copper and dissolved zinc) stormwater treatment.

The sand filters at both the Boulder Creek Upper and Boulder Creek Lower sites were designed as large sand filters per the 1998 KCSWDM. The sand filter at the Boulder Creek Upper location is 170-feet long by 26-feet wide, providing 4,400 square feet of filter area. The sand filter at the Boulder Creek Lower location is 50 feet long by 10 feet wide, providing 500 square feet of filter area. Both sand filters are sized to treat 95 percent of runoff volumes at the site. The 5 percent of high flows greater than this volume bypass the sand filters through the emergency overflow structures in the upstream pre-settling detention basins (described in Sections 2.2.1.1 and 2.2.1.2).

The sand filters are comprised of three layers. The top layer is sand, the middle layer is a geotextile fabric and the bottom layer is gravel with an underdrain pipe system. The specifications for the sand layer are presented in Table 1. The geotextile fabric design criteria are presented in Table 2. The sand filters at both the Upper and Lower sites have flow spreaders for erosion protection and even distribution of the inflow.

Table 1. Sand media specifications for sand filters installed at the Boulder Creek Upper and Lower monitoring facilities

U.S. Sieve Size	Percent Passing
U.S. No. 4	95 to 100 percent
U.S. No. 8	70 to 100 percent
U.S. No. 16	40 to 90 percent
U.S. No. 30	25 to 75 percent
U.S. No. 50	2 to 25 percent
U.S. No. 100	Less than 4 percent
U.S. No. 200	Less than 2 percent

Table 2. Geotextile for sand filters installed at the Boulder Creek Upper and Lower monitoring facilities

Geotextile Property	Value	Test Method
Grab strength (lbs)	75 (min)	ASTM D4632
Burst strength (psi)	130 (min)	ASTM D3786
Trapezoid tear (lbs)	40 (min)	ASTM D4533
Permeability (cm/sec)	0.2 (min)	ASTM D4491
AOS (sieve size)	#60-#70	ASTM D4751
Ultraviolet resistance	70 percent or greater	ASTM D4355

Notes:
*Acceptability of geotextile material shall be based on ASTM D-4759
*Minimum values should be in the weaker principle direction. All numerical values represent minimum average roll value (i.e. test results from any sampled lot shall meet or exceed the minimum values in the table). Stated values are for noncritical and nonsevere applications.

2.3 Sample Design

Flow data, water quality samples, and sediment samples were collected at both the Boulder Creek Upper and Boulder Creek Lower BMP facilities. Flow data and water quality samples were collected each of the following locations:

(1) inflow to the Pre-Settling Detention Basin
   Boulder Creek Upper Pond Inlet (UPIN)
   Boulder Creek Lower Vault Inlet (LVIN)
(2) outflow from Pre-Settling Detention Basin (also represents flow into the Large Sand Filters)
   Boulder Creek Upper Pond Outlet (UPOL)
   Boulder Creek Lower Vault Outlet (LVOL)
(3) outflow from the Large Sand Filters
   Boulder Creek Upper Sand Filter Outlet (USFOL)
   Boulder Creek Lower Sand Filter Outlet (LSFOL)

Sediment samples were collected annually at any location with accumulated sediment, as described in Section 3.3. The sampling locations are shown in Figures 2 and 3.

Figure 2. Boulder Creek Upper BMP Monitoring Location

Figure 3. Boulder Creek Lower BMP Monitoring Location

2.3.1 Initial Sample Size Determination

Sampling design for evaluation of the BMPs was based on Draft Modification: Evaluating Stormwater Treatment Technologies with Long Detention Times – Technology Assessment Protocol – Ecology (Ecology, 2008b). This calls for influent and effluent storm flow samples to be collected independently on randomly selected days. A sufficiently large data set is required to compare influent and effluent data collected using random sampling techniques. The initial sample size was set at 15 samples from each monitoring location, with additional samples targeted as necessary to meet the statistical goals or reach the maximum of 35 influent and effluent samples for each permit required parameter.

2.3.2 Target Sample Events

Sampling following the random sampling approach took place during pre-selected 24-hour periods (sample events) between October 1, 2009 and December 31, 2011. As described in Section 2.3.1, the initial sample size was set as 15 successful sample events for each of the sampling locations.

Storm runoff must occur during a sample event, so sample event selection had to account for days when insufficient runoff may occur. Rainfall data collected at the Mystic Lake rain gauge between October 1, 2000 and September 30, 2008 was analyzed to determine the percentage of time there was expected to be storm flow at the monitoring sites, and subsequently how many days would need to be targeted to collect 15 samples at each monitoring site. Based on the analysis of the rain data, it was determined that 83 randomly selected days should be targeted in order to collect 15 storm flow samples.

The scheduled sampling days were stratified by wet season (October 1 through March 31) and dry season (April 1 through September 30) to ensure that sample days were proportional to seasonal rainfall. Based on the rainfall record, 70 percent, or 58 days, were targeted during October 1 and March 31 (wet season), and 30 percent, or 25 days, were targeted during April 1 and September 30 (dry season) to achieve a goal of collecting 10 samples during the wet season and 5 samples during the dry season.

A separate schedule of randomly selected days was developed for the pre-settling detention facility inflow and outflow monitoring stations. The sand filter outflow monitoring stations were sampled on the same days as the pre-settling detention facility basin outflow monitoring stations (which also represents flow into the sand filters). The random sampling schedule is presented in Appendix C.

For samples collected following the random sampling approach, there is no minimum rainfall depth or dry antecedent requirement defining a “qualifying sample event”. The only criterion for a qualifying sample event, as stated in the *TAPE* protocols for long detention BMPs, is the presence of storm flow during the 24-hour sample event period (Ecology, 2008b). Auto samplers were used to collect flow-weighted composite samples representing up to 24-hour periods on the scheduled sampling days. If no flow was recorded on a scheduled sampling day, then the samplers were retrieved and set up for the next scheduled sampling day.

2.4 Sampling Procedures

The following sections describe the stormwater and sediment sampling procedures performed by King County staff as part of the BMP monitoring. All sampling procedures were conducted following the project QAPP.

2.4.1 Stormwater Sampling Procedures

Automated flow-weighted stormwater composite samples were collected at each site to evaluate the effectiveness of two types of BMPs: a pre-settling detention basin and a large sand filter. The following section describes the monitoring equipment and sampling and handling procedures used for the project.

2.4.1.1 Monitoring Equipment

Automated composite samplers and flow monitoring equipment were installed at each of the BMP monitoring sites, at locations shown in Figures 2 and 3. To meet the requirement that flow through the BMPs be measured for a year before sampling begins, water level and pressure sensors were installed on November 12, 2008 at five of the six monitoring locations.

- Boulder Creek Upper Pond Inlet (UPIN)
- Boulder Creek Upper Pond Outlet (UPOL)
- Boulder Creek Upper Sand Filter Outlet (USFOL)
- Boulder Creek Lower Vault Inlet (LVIN)
- Boulder Creek Lower Vault Outlet (LVOL)

At the five locations an Onset model U20-004 sealed pressure sensor was installed. This sensor records total pressure (water pressure plus barometric pressure) and water temperature at 15 minute intervals. A second Onset model U20 sensor was installed to record barometric pressure, which was used to calculate water level from the total pressure record.

At the Boulder Creek Lower Sand Filter Outlet (LSFOL) site the manhole lid covering the monitoring location was buried and inaccessible. Initial site visits also indicated that the LSFOL site was not functioning as expected. Lower flow volumes than expected were observed entering the lower sand filter. When the lower sand filter outlet basin was checked, it was discovered that flow was exiting the vault through a poorly sealed slide gate into the overflow outlet. This resulted in flows bypassing the sand filter. By late winter of water year 2010, the gate was fixed and flow was able to discharge through the control structure.

Flow monitoring and water sampling equipment was installed in September 2009 at the three Boulder Creek Upper BMP sites (UPIN, UPOL, and USFOL). Flow monitoring equipment at the UPIN site consisted of an Isco 4250 area velocity meter installed in an 18-inch pipe. At the UPOL site an Isco 4230 bubbler flow meter was installed behind a multiple orifice control structure. Flow was measured at the USFOL site using an Isco 4230 bubbler flow meter installed behind an inlet controlled 12-inch diameter round pipe. At each site the water sampling equipment consisted of a Teledyne-Isco 3700 series autosampler, the sampler suction line, and sampler strainer.

Due to the maintenance at the LSFOL site mentioned above, the Boulder Creek Lower BMP sites (LVIN, LVOL, and LSFOL) were still not functioning properly in September 2009. Equipment installation at those sites was staggered over the succeeding months. Flow and water quality equipment was installed at the LVOL site in October 2009, at the LVIN site in January 2010, and at the LSFOL site in February 2010. Flow monitoring equipment at the LVOL site consisted of an Isco 4230 bubbler flow meter installed behind a multiple orifice control structure. At the LVIN site an Isco 4230 bubbler flow meter was installed behind an inlet controlled 12-inch diameter round pipe. Flow was measured at the LSFOL site using an Isco 4250 area velocity meter installed in a 12-inch pipe. As with the Upper BMP sites, at each Lower BMP site the water sampling equipment consisted of a Teledyne-Isco 3700 series autosampler, the sampler suction line, and sampler strainer.

A rain gage was installed at the Boulder Creek Upper BMP and was used as a project rain gage for all six monitoring sites. The rain gage is a Hydrological Services TB3 0.01” tipping bucket rain gage, which was installed with a Campbell Scientific CR200 data logger. The rain gage recorded each tip of rain with the data logger logging 15-minute rain totals. A Raven GPRS modem allowed for the automated hourly download of the rain data to a computer at the King County Water and Land Resources Division King Street office, and automatically loaded the data into the Hydrologic Information Center database.

2.4.1.2 Stormwater Sample Collection & Handling

For the collection of grab and automated composite samples, sampling staff consulted the randomly generated sampling schedule (Appendix C). Sampling staff then made a determination as to whether or not there was, or was predicted to be, adequate storm flow through the BMP facility to collect a water quality sample on the randomly selected sampling day. If so, field staff set up the appropriate sites for the upcoming event.

For each targeted event, samples were retrieved at the end of the 24-hour period. Sampling staff then reviewed event data to determine if the sampled event met project the guideline that samples should represent storm flow and not include base flow. Upon confirmation that this sampling event guideline was met, samples were field processed and prepared for transport to the laboratory for analysis. The project analytical parameters, methods, method detection limits, report detection limits, and practical quantification limits are presented in Table 3.

2.4.1.3 In-situ (field) Data

In addition to the samples collected for laboratory analysis, a multiprobe was be used to collect pH and temperature data directly from the samples while in the field. Field notes were maintained for all field activities, both the collection of samples and the gathering of environmental data.

2.4.1.4 Decontamination Procedures

Once samples were collected, all re-usable equipment was decontaminated with wash and rinse water. EPA approved detergents and de-ionized water (ASTM I or II) were used to provide efficient decontamination of equipment. Equipment blanks were analyzed to check for possible cross contamination between sampling events.

2.4.1.5 Quality Assurance Quality Control (QA/QC) Samples

Stormwater samples were filtered in the field for dissolved metals and orthophosphate. As part of project QA/QC techniques, field filtration blanks were collected to check the cleanliness of the filtration equipment or procedures. Field filtration blanks were generated by carrying reverse osmosis water into the field and pouring it through the filtration equipment into a sample container. The results of the field filtration blanks may indicate the presence of contamination due to sample collection and handling procedures or to conditions in the field.

As mentioned in Section 2.4.1.4, equipment blanks were analyzed to check for possible cross contamination between sampling events.

Table 3. Parameters, Methods, and Detection Limits for Water Samples

Water Quality Parameters	Method	Method Detection Limit	Reporting Detection Limit
Total suspended solids (TSS)	SM2540D	0.5 mg/L	1.0 mg/L
Particle size distribution (PSD)	Laser diffraction	0.1%	NA
pH	SM4500-H-B	NA	NA
Hardness as CaCO3	EPA 200.8/ SM2340B.ED19	0.066 mg/L	0.33 (mg $CaCO_3$/L)
Total phosphorus (Total-P)	SM4500-P-B,F	0.005 mg/L	0.01 mg/L
Orthophosphate Phosphorus (Ortho-P)	SM4500-P-F	0.002 mg/L	0.005 mg/L
Fecal coliform	SM9222D	1 cfu/100mls	1 min., 1E6 max cfu/100mls
NWTPH-Dx (TPH) Diesel Range	NWTPH-Dx	0.2 mg/L	0.2 mg/L
NWTPH-Dx (TPH) Lube Oil Range	NWTPH-Dx	0.2 mg/L	0.2 mg/L
Total zinc (Zn)	EPA 200.8	0.081 ug/L[a]	2.5 ug/L[b]
Dissolved zinc	EPA 200.8	0.081 ug/L[a]	2.5 ug/L[b]
Total copper* (Cu)	EPA 200.8	0.043 ug/L[a]	2.0 ug/L[b]
Dissolved copper*	EPA 200.8	0.043 ug/L[a]	2.0 ug/L[b]
Total calcium (Ca)	EPA 200.8	10 ug/L	50 ug/L
Total magnesium (Mg)	EPA 200.8	10 ug/L	50 ug/L

(a) Method Detection Limit: King County Environmental Laboratory's empirically derived EPA 40 CFR MDL. Changes at least annually when MDL studies are performed. These values do not show up on any reported data.

(b) King County Environmental Laboratory reporting detection limit for total and dissolved zinc is 0.5 ug/L and for total and dissolved copper is 0.4 ug/L. Value listed for total and dissolved zinc and copper is considered the Practical Quantitation Limit: King County Environmental Laboratory's limit for accurate quantification as defined by EPA SW846 procedures. A low level check standard at or near this concentration must yield +/- 30% of the True Value. King County Environmental Laboratory reports show this as the "LIMS RDL".

* King County Environmental Laboratory reporting limit for total and dissolved copper is 0.4 ug/L using EPA method 200.8 without using a "clean hands/dirty hands" method based upon EPA 1669 sample collection for ultra low trace metals. Automated samplers are not suitable for ultra low detection limits. Therefore, this slightly higher reporting limit will be used for this project.

2.4.2 Sediment Sampling Procedures

Sediment samples were collected annually at each site that had accumulated sediment. Samples were collected using a Ponar® grab sampler. The Ponar® sampler was cast one or more times at each location as necessary to obtain adequate sample volume for laboratory analyses. Table 4 lists the parameters, methods, and detection limits for sediment samples.

Table 4. Parameters, Methods, and Detection Limits for Sediment Samples

Sediment Quality Parameters	Method	Method Detection Limit (wet weight)	Reporting Detection Limit (wet weight)
Total solids	SM 2540-G	0.005%	0.01%
Grain size[(a)]	ASTM D422	Sieve (Gravel & Sand) 0.1% Hydrometer (Silt & Clay) 0.5 %	1.0% for all categories
Total Volatile Solids	SM 2540-G	0.005%	0.01%
NWTPH-Dx Diesel Range	NWTPH-Dx	25 mg/Kg	25 mg/Kg
NWTPH-Dx Lube Oil Range	NWTPH-Dx	25 mg/Kg	25 mg/Kg
Total phosphorus	EPA 3050B/6010A	25 mg/kg	125 mg/kg
Total cadmium	EPA 3050B/6010A	0.01 mg/kg	0.5 mg/Kg
Total copper	EPA 3050B/6010A	0.2 mg/kg	1.0 mg/Kg
Total lead	EPA 3050B/6010A	1.0 mg/kg	5.0 mg/Kg
Total zinc	EPA 3050B/6010A	0.25 mg/kg	1.25 mg/Kg

(a) The MDL and RDL values for grain size will be different for each sample, depending on the amount of solids analyzed for each.

3.0. COMPREHENSIVE DATA REPORT

This section presents details about the storm and sediment events sampled at the Boulder Creek Upper and Boulder Creek Lower BMP sites. It also provides information on the operation and maintenance activities and capital and project annual costs.

3.1 Summary of Sample Events

Sample events were targeted for sampling between October 2009 and December 2011. As stated in Section 2.3.2, there is no minimum rainfall depth or dry antecedent requirement defining a “qualifying sample event”. The only criterion for a qualifying sample event, as stated in the *TAPE* protocols for long detention BMPs, is the presence of storm flow during the 24-hour sample event period (Ecology, 2008b). Due to the random sampling schedule, the number of samples collected to date varies with sampling location.

Table 5 presents the total number of samples collected, and the total number of samples meeting TAPE guidelines, for each of the six sampling sites. TAPE guidelines state “as a guideline, at least 10 aliquots should be composited, covering at least 75% of each storm’s total runoff volume” (Ecology, 2008a). A detailed look at the sample event characteristics and how they compared to TAPE guidelines is provided in Tables 6 through 11.

Table 5. Number of sampled and valid events at UPIN, UPOL, USFOL, LVIN, LVOL, and LSFOL monitoring sites.

Station	Total # of Samples Collected	Total # of Samples Meeting TAPE Guidelines[1]
UPIN	23	8
UPOL	33	15
USFOL	26	6
LVIN	17	3
LVOL	21	5
LSFOL	17	5

[1]TAPE states “As a guideline, at least 10 aliquots should be composited, covering at least 75% of each storm’s total runoff volume.” (Ecology, 2008a)

Table 6. Sample Event Characteristics for UPIN site.

	Rainfall total (in)	Storm duration (hrs)	Sampling duration (hrs)	Peak flow rate (gpm)	Number of aliquots	24 hour runoff volume (gal)	Runoff volume sampled (gal)	Percent runoff sampled
TAPE Guideline	NA	NA	>1	NA	≥ 10	NA	NA	≥ 75
10/14/09	0.96	20.5	12.6	1200	25	124315	101196	81
11/17/09	0.88	18.0	18.6	225	25	91137	55906	61
11/19/09	0.89	23.25	2.6	160	7	72408	14623	20
12/21/09	0.67	8.75	8.9	235	15	69183	41627	60
1/4/10	0.81	22.75	4.7	120	11	63393	25624	40
1/13/10	1.01	23.25	6.9	210	25	91925	57933	63
2/24/10	0.24	16.75	2.3	140	3	64342	10718	17
9/1/10	0.04	1.0	3.5	33	2	10085	2249	22
9/17/10[1]	0.44	9.3	7.7	--	8	--	--	--
11/1/10	1.34	13.75	6.15	399	25	115780	50883	44
11/30/10	0.77	23.25	13.97	94	18	45828	32731	71
12/13/10	0.39	21.75	7.87	1127	25	131903	78494	60
1/13/11	0.80	20.5	8.35	180	25	112204	52383	46
1/21/11	1.29	24.0	10.33	224	25	136495	44801	33
3/2/11	0.15	12.25	12.67	85	7	12312	11637	95
3/16/11	0.19	20.75	22.18	193	20	44589	40024	90
3/29/11	0.47	24	18.1	102	11	23626	20691	88
4/4/11	0.59	20.25	13.26	212	18	48781	36543	75
4/25/11	0.40	12.75	3.8	122	7	21296	13607	64
5/31/11	0.17	15.5	3.28	152	4	7520	7405	98
11/2/11	0.01	0.08	15.3	323	15	32254	31886	99
11/16/11	0.27	8.0	13.1	427	10	26598	20078	75
11/21/11	0.54	19.0	25.82	281	25	60495	56833	94

Notes:
[1] Level and flow data from 9/17/10 sample event was lost therefore peak flow rate, 24 hour runoff volume and runoff volume sampled could not be calculated.

Table 7. Sample event characteristics from UPOL site.

	Rainfall total (in)	Storm duration (hrs)	Sampling Duration (hrs)	Peak flow rate (gpm)	Number of aliquots	24 hour runoff volume (gal)	Runoff volume sampled (gal)	Percent runoff sampled
TAPE Guidelines	NA	NA	>1	NA	≥ 10	NA	NA	≥ 75
10/14/09	0.81	18.5	7.2	120	25	141651	47733	34
10/21/09	0.46	14.5	22.6	100	25	36827	36288	99
11/5/09	0.57	10.0	21.2	104	25	49012	43357	88
11/18/09	0.33	23.15	6.9	114	25	110009	51773	47
12/20/09	0.38	20.75	22.9	108	25	38779	34066	88
1/4/10	0.80	20.5	11.7	106	25	101728	46656	46
1/14/10	0.35	6.75	6.5	117	25	159223	48272	30
2/11/10	0.31	27.5	30.7	9	14	10570	10570	100
3/3/10	0.01	0.08	34.8	13	14	11109	11109	100
4/22/10	0.0	0.0	13.2	96	25	57889	52648	91
5/19/10	0.44	18.45	22.0	94	25	42549	39991	94
6/10/10	0.29	20.0	12.6	36	15	20534	10637	52
9/16/10	0.44	9.5	7.4	100	19	28546	23362	82
11/1/10	1.34	13.75	9.35	130	24	115985	40035	35
11/8/10	0.06	0	48.5	9	22	15063	15063	100
11/18/10	0.17	22.5	10.92	49	11	15186	8675	57
12/7/10	0.30	6.5	21.0	49	19	21629	20291.43	94
12/15/10	0.10	5.75	3.9	207	25	283105	47694	17
1/12/11	1.17	22.0	6.4	112	25	135430	44829	33
1/21/11	1.29	24.0	6.02	130	25	164779	45718	28
2/7/11	0.05	16.5	7.33	14	7	13976	3945	28
3/9/11	1.12	22.0	10.42	94	25	95766	41827	44
3/14/11	0.27	19.5	5.13	144	25	205707	44183	21
4/4/11	0.59	20.25	4.72	162	25	228600	44403	19

	Rainfall total (in)	Storm duration (hrs)	Sampling Duration (hrs)	Peak flow rate (gpm)	Number of aliquots	24 hour runoff volume (gal)	Runoff volume sampled (gal)	Percent runoff sampled
TAPE Guidelines	NA	NA	>1	NA	≥ 10	NA	NA	≥ 75
4/27/11	0.40	21.0	11.78	99	25	51377	38825	76
5/25/11	0.37	6.5	11.4	99	23	42792	34729	81
9/26/11	0.43	17.75	25.9	5	30	10463	6966	67
10/21/11	0.18	17.0	32.57	94	21	21888	21764	99
11/2/11	0.01	0.25	22.9	104	25	37217	36770	99
11/15/11	0.01	0.25	35.78	49	17	12738	11981	94
11/21/11	0.53	14.5	18.03	92	25	54017	23781	44
11/29/11	0.14	8.25	21.27	35	14	13824	9312	67
12/15/11	0.20	20.75	57.75	18	24	17594	16676	95

Table 8. Sample event characteristics for USFOL site.

	Rainfall total (in)	Storm duration (hrs)	Sampling Duration (hrs)	Peak flow rate (gpm)	Number of aliquots	24 hour runoff volume (gal)	Runoff volume sampled (gal)	Percent runoff sampled
TAPE Guidelines	NA	NA	>1	NA	≥ 10	NA	NA	≥ 75
10/14/09	0.66	13.75	4.7	250	25	305728	47713	16
10/21/09	0.37	9.5	12.6	210	25	133963	51739	39
11/5/09	0.93	20.25	4.6	250	25	287402	53833	19
11/18/09	0.33	23.25	2.5	308	25	411563	54789	13
12/20/09	0.38	20.75	12.3	228	25	164447	53671	33
1/4/10	0.86	22.75	11.2	120	25	126968	51712	41
1/14/10	0.35	6.75	4.4	176	25	251976	61656	24
2/11/10	0.20	19.25	24.6	11	6	8914	8604	97
3/3/10	0.01	0.08	31.0	62	12	18959	21329	113
4/22/10	0.0	0.00	5.8	134	25	169921	46508	27
5/19/10	0.46	10.75	21.8	124	25	56512	50393	89
6/10/10	0.29	20.0	13.0	114	25	81860	49127	60
9/17/10	0.44	9.5	31.2	130	25	46084	46084	100
11/1/10	1.34	13.75	12.6	178	25	144081	48244	33
11/8/10	0.09	2.5	45.68	18	17	23495	23495	100
11/18/10	0.17	22.5	11.63	83	23	58058	37481	65
12/7/10	0.00	0.00	18.58	68	9	15706	14928	95
12/15/10	0.10	5.75	3.82	197	25	275784	44143	16
1/12/11	1.13	19.75	6.73	119	25	128109	44472	35
1/21/11	0.16	4.25	6.53	128	25	150337	44946	30
2/7/11	0.05	16.5	6.42	73	5	33408	6505	19
3/9/11	1.12	22.0	7.92	82	16	86782	29412	34
3/14/11	0.27	19.5	5.32	143	25	190800	43855	23
4/4/11	0.59	20.25	5.02	150	25	211430	44529	21

	Rainfall total (in)	Storm duration (hrs)	Sampling Duration (hrs)	Peak flow rate (gpm)	Number of aliquots	24 hour runoff volume (gal)	Runoff volume sampled (gal)	Percent runoff sampled
TAPE Guidelines	**NA**	**NA**	**>1**	**NA**	**≥ 10**	**NA**	**NA**	**≥ 75**
4/27/11	0.39	18.75	15.97	79	25	47339	42745	90
5/25/11	0.37	6.5	9.2	86	25	44448	43619	98

Table 9. Sample event characteristics for LVIN site.

	Rainfall total (in)	Storm duration (hrs)	Sampling Duration (hrs)	Peak flow rate (gpm)	Number of aliquots	24 hour runoff volume (gal)	Runoff volume sampled (gal)	Percent runoff sampled
TAPE Guidelines	**NA**	**NA**	**>1**	**NA**	**≥ 10**	**NA**	**NA**	**≥ 75**
1/13/10	0.97	23.0	15.7	64	25	13802	1616	12
2/24/10	0.40	16.5	12.2	41	25	3770	1750	46
11/1/10	1.34	13.75	7.3	251	25	96687	6297	7
11/30/10	0.77	24.25	2.48	117	25	62291	6947	11
12/13/10	0.00	0.00	7.13	242	25	42193	20078	48
12/28/10	0.30	8.25	12.73	36	10	15906	8260	52
1/13/11	0.00	0.00	2.37	162	25	82722	14832	18
1/21/11	0.16	4.0	6.68	171	25	113136	18909	17
3/2/11	0.15	12.25	18.57	72	13	17636	15182	86
3/16/11	0.19	20.75	16.93	139	25	23160	18553	80
3/29/11	0.47	24.0	21.78	90	21	22161	20002	90
4/4/11	0.59	20.25	10.03	162	25	33541	23951	71
4/25/11	0.40	12.75	5.33	103	21	20165	12364	61
5/31/11	0.17	15.5	1.02	126	8	4725	4444	94
9/26/11	0.43	17.75	24.6	63	27	23579	8689	37
11/2/11	0.01	0.25	1.22	236	25	25489	12370	49
11/14/11	0.10	4.75	3.43	56	11	6921	4156	60

Table 10. Sample event characteristics for LVOL site.

	Rainfall total (in)	Storm duration (hrs)	Sampling Duration (hrs)	Peak flow rate (gpm)	Number of aliquots	24 hour runoff volume (gal)	Runoff volume sampled (gal)	Percent runoff sampled
TAPE Guidelines	NA	NA	>1	NA	≥ 10	NA	NA	≥ 75
2/11/10[1]	0.31	29.25	31.3	--	16	--	--	--
3/3/10[1]	0.00	0.00	31.9	--	13	--	--	--
4/22/10	0.00	0.00	7.9	9	25	10637	4847	46
5/19/10	0.00	0.00	9.0	9	25	7810	3972	51
6/10/10	0.29	20.0	10.5	9	25	6463	2962	46
9/18/10	0.60	24.0	8.1	5	17	2760	2424	88
11/1/10	1.34	20.5	12.75	14	25	11179	2775	25
11/8/10	0.00	0.00	10.96	5	25	2950	2950	100
11/15/10	0.17	12.75	9.92	5	10	2755	533	10
11/18/10	0.17	22.5	10.63	5	19	4032	2860	19
12/15/10	0.10	5.75	8.17	5	25	6655	4060	61
1/12/11	1.17	22.0	8.13	9	25	9650	4375	45
1/21/11	1.29	24.0	5.75	9	25	11314	3093	27
3/9/11	1.12	22.0	6.82	9	9	7520	1766	23
3/14/11	0.27	19.5	6.07	9	25	12911	3264	25
4/4/11	0.59	20.25	7.28	9	25	12911	3918	30
4/27/11	0.38	23.0	13.27	5	19	2555	2555	100
5/25/11	0.37	6.5	10.67	5	25	2891	2869	99
11/2/11	0.42	18.0	3.60	6	8	4659	761	16
11/21/11	0.00	0.00	16.23	7	26	7524	7524	100
11/29/11	0.40	10.0	10.57	6	25	4459	2842	64

Notes:
[1] No flow data for the 2/11/10 and 3/3/10 sample events due to equipment errors.

Table 11. Sample event characteristics for LSFOL site.

	Rainfall total (in)	Storm duration (hrs)	Sampling Duration (hrs)	Peak flow rate (gpm)	Number of aliquots	24 hour runoff volume (gal)	Runoff volume sampled (gal)	Percent runoff sampled
TAPE Guidelines	NA	NA	>1	NA	≥ 10	NA	NA	≥ 75
11-Feb-10	0.24	22.5	19.6	3.6	4	99	59	60
3-Mar-10	0.02	0.75	23.2	0.9	5	41	41	100
19-May-10	0.26	18.25	16.6	2.5	7	74	60	81
10-Jun-10	0.29	20.0	2.8	0.6	3	40	27	68
17-Sep-10	0.44	9.5	28.8	1.4	6	37	37	100
1-Nov-10	1.34	13.75	17.33	14	24	1065	1065	100
18-Nov-10	0.17	22.5	4.67	5	7	67	66	99
Dec-10	1.01	17.5	17.97	9	20	3295	2995	91
12-Jan-11	1.17	22.0	4.95	9	25	10715	2663	25
21-Jan-11	1.29	24.0	4.08	9	25	11646	2197	19
9-Mar-11	1.12	22.0	10.62	9	12	7919	2856	36
14-Mar-11	0.88	40.75	27.65	9	25	12162	8181	67
4-Apr-11	0.58	18.75	12.05	5	12	6455	1614	25
25-May-11	0.37	6.5	12.42	5	5	1143	1136	99
21-Oct-11	0.18	17.0	23.22	6	14	67	67	100
2-Nov-11	0.54	10.25	9.06	15	21	677	677	100
21-Nov-11	0.54	19.0	19.25	11	25	1340	1143	85

3.2 Characteristics of Individual Sampled Events

Continuous precipitation and flow data were collected throughout the project, and sample event information was documented for all sampled events. Sample event files presenting the storm flow hydrographs for each sample event are included in Appendix D. The analytical results from the grab and composite samples collected during sampled events are summarized for each site in Table 12 through Table 17. Analytical laboratory reports for each event are included electronically on an included cd as Appendix E.

3.2.1 Boulder Creek Upper Pond Inlet (UPIN)

The analytical results for samples collected at the UPIN site are provided in Table 12. For this site, conventional, metals and nutrient concentrations were above the method detection limit (MDL) for all 23 composite samples. In addition, all samples were above the reporting detection limit (RDL) for all but the following parameters:

- Orthophosphate phosphorus was below the RDL for one sample
- Total copper was below the RDL for eight samples
- Dissolved copper was below the RDL for fifteen samples

There were 25 grab samples collected for lube oil and diesel analysis, and 18 grab samples collected for fecal coliform analysis. For the grab samples, lube oil concentrations were below the MDL for all but five of the samples, while diesel range concentrations were below the MDL for all samples. Fecal coliform concentrations were above the MDL for all samples.

3.2.2 Boulder Creek Upper Pond Outlet (UPOL)

For the UPOL site, with the exception of one dissolved copper sample, conventional, metals and nutrient concentrations (Table 13) were above the MDL for all 32 composite samples. In addition, all samples were above the reporting detection limit (RDL) for all but the following parameters:

- TSS was below the RDL for three samples
- Orthophosphate phosphorus was below the RDL for three samples
- Total copper was below the RDL for 24 samples
- Dissolved copper was below the RDL for 30 samples
- Total zinc was below the RDL for four samples
- Dissolved zinc was below the RDL for 15 samples.

There were 33 grab samples collected for lube oil and diesel analysis, and 23 grab samples collected for fecal coliform analysis. For the grab samples, lube oil concentrations and diesel range concentrations were below the MDL for all samples. Fecal coliform grab samples were above the MDL for all but one sample.

3.2.3 Boulder Creek Upper Sand Filter Outlet (USFOL)

For the USFOL site, TSS concentrations were below the MDL for 13 of the 27sampling events and dissolved zinc was below the MDL for one sampling event (Table 14). All other conventional, metals and nutrient concentrations were above the MDL for all composite samples. In addition, all samples were above the reporting detection limit (RDL) for all but the following parameters:

- TSS was below the RDL for ten samples
- Total phosphorus was below the RDL for five sample
- Orthophosphate phosphorus was below the RDL for one sample
- Total copper was below the RDL for 15 samples
- Dissolved copper was below the RDL for 18 samples
- Total and dissolved zinc were below the RDL for 23 samples

There were 26 grab samples collected for lube oil and diesel analysis, and 16 grab samples collected for fecal coliform analysis. For the grab samples, lube oil concentrations and diesel range concentrations were below the MDL for all samples. Fecal coliform concentrations were below the MDL for four samples.

Table 12. Sampling Analytical Results for UPIN

Sample Date	pH	TSS (mg/L)	PSD (mean size)[1] (µm)	Total-P (mg/L)	Ortho-P (mg/L)	Hardness (mg/L)	Total Cu (mg/L)	Diss. Cu (mg/L)	Total Ca (mg/L)	Total Mg (mg/L)	Total Zn (mg/L)	Diss. Zn (mg/L)	Temp. (˚C)	TPH Diesel (mg/L)	TPH Oil (mg/L)	Fecal Coliform (cfu/ 100mls)
10/14/09	--	72.3	10	0.244	0.0512, H	8.92	0.00858	0.001, <RDL,H	2.41	0.705	0.0586	0.00529, H	--	<0.19	0.266	--
11/17/09	7.13	6.39	12.34	0.0368	0.0182, H	18.1	0.0012, <RDL	0.00069, <RDL,H	5.32	1.17	0.00837	0.00475, H	10.5	<0.19	<0.19	--
11/19/09	6.72	5.29	10.52	0.0359	0.0125	12.2	0.00097, <RDL	0.00048, <RDL	3.69	0.728	0.00826	0.00462	8.57	<0.19	<0.19	--
12/21/09	6.8	5.6	8.38	0.0295	0.0109, H	17.7	0.00461	0.00301, H	5.16	1.16	0.00867	0.00527, H	3.6	<0.19	<0.19	--
1/4/10	6.8	7.6	12.2	0.0271	0.00837, H	11.1	0.0014, <RDL	0.00071, <RDL,H	3.29	0.69	0.0105	0.00615, H	9.68	<0.19	<0.19	--
1/13/10	6.84	6.9	10.2	0.0328	0.0129, H	17.5	0.0014, <RDL	0.00088, <RLD,H	5.07	1.16	0.00898	0.00515, H	9.3	<0.19	<0.19	--
2/24/10	6.63	38.8	--	0.127	0.0045, <RDL,H	11.5	0.00826	0.00371, H	3.52	0.649	0.037	0.0121, H	11.1	<0.19	<0.19	--
9/1/10	7.06	5.6	--	0.0536	0.0246, H	74.9	0.00396	0.00308, H	22.1	4.81	0.0149	0.0139, H	16.2	<0.19	<0.19	1100
9/17/10	6.95	114	--	0.202	0.0192, H	21	0.0151	0.00371, H	5.83	1.56	0.0602	0.00702, H	16	<0.19	<0.19	5500
11/1/10	6.87	17.5	--	0.0678	0.0273, H	13.5	0.002, <RDL	0.0013, <RDL,H	3.94	0.894	0.0117	0.00671, H	13	<0.19	<0.19	1100
11/30/10	6.58	12.2	--	0.0548	0.0145, H	16.3	0.00246	0.0011, <RDL,H	4.9	0.994	0.0124	0.00639, H	7	<0.19	<0.19	600
12/13/10	6.94	6.7	--	0.0363	0.0126, H	41.3	0.0017, <RDL	0.001, <RDL,H	11.7	2.95	0.0215	0.00427, H	9.3	<0.19	<0.19	2300
1/13/11	6.3	17.2	--	0.0463	0.0158, H	26.1	0.00227	0.00074, <RDL,H	7.57	1.75	0.0112	0.00533, H	8.4	<0.19	<0.19	73
1/21/11	7.22	11.7	--	0.0469	0.021, H	33.6	0.00222	0.00098, <RDL,H	9.58	2.35	0.00912	0.00383, H	9.1	<0.19	<0.19	1500
3/2/11	6.7	13.8	--	0.0462	0.008, H	41.2	0.00313	0.0015, <RDL,H	11.5	3.01	0.0134	0.00623, H	9.2	<0.19	0.223	9
3/16/11	7.1	2.5	--	0.0252	0.0123, H	46.6	0.0012, <RDL	0.00094, <RDL,H	13.4	3.22	0.00544	0.00449, H	8.6	<0.19	<0.19	13
3/29/11	5.6	5.1	--	0.0349	0.0141, H	15.1	0.00434	0.0024, H	4.44	0.983	0.00926	0.00703, H	12.4	<0.19	<0.19	160
4/4/11	7.21	4.7	--	0.0286	0.0118, H	29.5	0.0018, <RDL	0.001, <RDL,H	8.37	2.09	0.00784	0.00467, H	8.7	<0.19	<0.19	14
4/25/11	6.58	5.2	--	0.0312	0.0102, H	13.3	0.00377	0.00218, H	3.89	0.874	0.0114	0.00862, H	10.5	<0.19	0.287	600
5/31/11	6.51	6.2	--	0.0492	0.0153, H	18.2	0.00464	0.00342, H	5.45	1.11	0.0159	0.010, H	12.5	<0.19	<0.19	1200
9/26/11	7.2	--	--	--	--	--	--	--	--	--	–	--	16.11	<0.19	0.237	1000

Sample Date	pH	TSS (mg/L)	PSD (mean size)[1] (µm)	Total-P (mg/L)	Ortho-P (mg/L)	Hardness (mg/L)	Total Cu (mg/L)	Diss. Cu (mg/L)	Total Ca (mg/L)	Total Mg (mg/L)	Total Zn (mg/L)	Diss. Zn (mg/L)	Temp. (˚C)	TPH Diesel (mg/L)	TPH Oil (mg/L)	Fecal Coliform (cfu/ 100mls)
11/2/11	7	18.9	--	0.134	0.0585, H	11.5	0.0048	0.0022, H	3.41	0.73	0.0229	0.0091, H	12.15	<0.19	<0.19	300
11/16/11	7.12	34.8	--	0.139	0.0468, H	15	0.00477	0.0017, <RDL,H	4.55	0.89	0.0293	0.00879, H	10.4	<0.19	<0.19	80
11/21/11	7.16	19.8	--	0.103	0.0361, H	13.4	0.00274	0.0012, <RDL,H	4.06	0.797	0.0232	0.0104, H	9	<0.19	<0.19	800
12/15/11	--	--	--	--	--	--	--	--	--	--	–	--	--	<0.19	0.2	11000

Notes

[1] PSD data was analyzed by two different laboratories during the project duration. The second laboratory (sample dates after Jan.13.10) did not report on the mean particle size. Full analytical reports from all PSD samples can be found in Appendix E.

"—" = no sample data

Values reported with "<RDL" indicate the target analyte was above the method detection limit but below the reporting detection limit.

Values reported with "<" indicate target analyte was not detected at reported value.

Values reported with "H" indicate the holding time was exceeded for that analyte.

Table 13. Sampling Analytical Results for UPOL

Sample Date	pH	TSS (mg/L)	PSD (mean size)[1] (µm)	Total-P (mg/L)	Ortho-P (mg/L)	Hardness (mg/L)	Total Cu (mg/L)	Diss. Cu (mg/L)	Total Ca (mg/L)	Total Mg (mg/L)	Total Zn (mg/L)	Diss. Zn (mg/L)	Temp. (˚C)	TPH Diesel (mg/L)	TPH Oil (mg/L)	Fecal Coliform (cfu/ 100mls)
10/14/09	--	4.51	6.65	0.133	0.0637, H	21.5	0.00216	0.0019, <RDL,H	5.98	1.58	0.00507	0.00452 , H	--	<0.19	<0.19	--
10/21/09	--	2.83	7.37	0.0459	0.0105	43.4	0.00077 , <RDL	0.00057 , <RDL	12.2	3.15	0.0019 , <RDL	0.0017, <RDL	--	<0.19	<0.19	--
11/5/09	--	3.4	11.98	0.055	0.00989, H	47.6	0.00063 , <RDL	0.00057, <RDL,H	12.8	3.8	0.0022 , <RDL	0.0012, <RDL,H	--	<0.19	<0.19	--
11/18/09	6.46	1.80	7.63	0.0327	0.0131, H	38.3	0.0012, <RDL	0.0011, <RDL,H	10.9	2.71	0.00357	0.00307 , H	7.98	<0.19	<0.19	--
12/20/09	6.41	2.20	9.45	0.0359	0.011, H	32	0.00436	0.0033, H	8.85	2.41	0.00353	0.00286 , H	2.4	<0.19	<0.19	--
1/4/10	6.47	8.98	21.48	0.0516	0.0098, H	31.2	0.0016, <RDL	0.00094, <RDL,H	8.63	2.34	0.00358	0.0018, <RDL,H	7.91	<0.19	<0.19	--
1/14/10	6.75	1.6, <RDL	8.55	0.0321	0.0108, H	31.3	0.0014, <RDL	0.0013, <RLD,H	8.9	2.2	0.0043	0.00347 , H	8.4	<0.19	<0.19	--
2/11/10	6.68	8.00	6.22	0.0626	0.0158, H	39.6	0.0013, <RDL	0.00079, <RDL,H	11.1	2.89	0.00449	0.00329 , H	6.6	<0.19	<0.19	--
3/3/10	6.73	6.60	16.72	0.0495	0.00936, H	34.9	0.0013, <RDL	0.00097, <RDL,H	9.55	2.68	0.0015 , <RDL	0.0011, <RDL,H	8.56	<0.19	<0.19	--
4/22/10	6.42	2.60	7.97	0.0316	0.00949, H	26.2	0.0016, <RDL	0.0013, <RDL,H	7.48	1.83	0.00404	0.0042, H	11.07	<0.19	<0.19	--
5/19/10	6.67	7.26	--	0.119	0.0474, H	48.8	0.0012, <RDL	0.00078, <RDL,H	13.8	3.49	0.00427	0.00267 , H	12.4	<0.19	<0.19	500
6/10/10	6.53	2.00	--	0.0531	0.00834, J,H	26	0.0018, <RDL	0.0013, <RDL,H	7.33	1.87	0.00355	0.0022, <RDL,H	15.6	<0.19	<0.19	130
9/16/10	6.8	5.52	--	0.0628	0.0182, H	49.1	0.002, <RDL	0.001, <RDL,H	13.6	3.66	0.0019 , <RDL	0.00087, <RDL,H	18.4	<0.19	<0.19	18
11/1/10	6.86	4.80	--	0.0558	0.0082, H	29.8	0.0014, <RDL	0.0011, <RDL,H	8.13	2.31	0.00562	0.00576 , H	12	<0.19	<0.19	800
11/8/10	6.85	10.80	--	0.0572	0.011, H	46.1	0.0017, <RDL	0.00091, <RDL,H	13.1	3.24	0.0052	0.0022, <RDL,H	7.9	<0.19	<0.19	3
11/18/10	6.83	5.60	--	0.045	0.012, H	34.2	0.00217	0.0016, <RDL,H	9.07	2.8	0.00482	0.00388 , H	7.6	<0.19	<0.19	46
12/7/10	6.83	9.60	--	0.0492	0.005, <RDL,H	73.7	0.0011, <RDL	0.00065, <RDL,H	21.5	4.86	0.00303	0.0012, <RDL,H	7.4	<0.19	<0.19	110
12/15/10	6.71	3.30	--	0.0364	0.013, H	32.2	0.0012, <RDL	0.00095, <RDL,H	9.26	2.2	0.00409	0.00311 , H	7.6	<0.19	<0.19	53
1/12/11	6.73	1.8, <RDL	--	0.0239	0.00614, H	28	0.0014, <RDL	0.00089, <RDL,H	8.73	1.5	0.00749	0.00609 , H	2.5	<0.19	<0.19	9
1/21/11	6.83	4.04	--	0.0325	0.0118, H	17.8	0.0011, <RDL	0.00065, <RDL,H	5.22	1.15	0.00692	0.0038, H	7.4	<0.19	<0.19	120
2/7/11	6.62	7.40	--	0.0485	0.0148, H	31.1	0.00098 , <RDL	0.00083, <RDL,H	8.8	2.22	0.00269	0.0015, <RDL,H	7.2	<0.19	<0.19	1

Sample Date	pH	TSS (mg/L)	PSD (mean size)[1] (µm)	Total-P (mg/L)	Ortho-P (mg/L)	Hardness (mg/L)	Total Cu (mg/L)	Diss. Cu (mg/L)	Total Ca (mg/L)	Total Mg (mg/L)	Total Zn (mg/L)	Diss. Zn (mg/L)	Temp. (˚C)	TPH Diesel (mg/L)	TPH Oil (mg/L)	Fecal Coliform (cfu/ 100mls)
3/9/11	6.99	7.20	--	0.0389	0.00686, H	48.8	0.0012, <RDL	0.00074, <RDL,H	14	3.38	0.00297	0.002, <RDL,H	8.6	<0.19	<0.19	<1
3/14/11	6.56	2.50	--	0.0299	0.00526, H	29.9	0.0015, <RDL	0.0013, <RDL,H	8.61	2.05	0.00509	0.00362, H	9.1	<0.19	<0.19	44
4/4/11	6.98	3.00	--	0.0236	0.007, H	36.2	0.0017, <RDL	0.0013, <RDL,H	10.2	2.57	0.00473	0.00372, H	8.1	<0.19	<0.19	42
4/27/11	7.26	1.8, <RDL	--	0.0614	0.02, <RDL,H	29.3	0.0016, <RDL	0.0014, <RDL,H	8.31	2.09	0.00305	0.0017, <RDL,H	12.2	<0.19	<0.19	5
5/25/11	6.93	4.20	--	0.107	0.034, H	37.6	0.0014, <RDL	0.0011, <RDL,H	10.6	2.69	0.00266	0.0017, <RDL,H	12.1	<0.19	<0.19	69
9/26/11	6.78	--	--	--	--	--	--	--	--	--	--	--	15.1	<0.19	<0.19	55
10/21/11	--	85.70	--	0.383	0.0068, H	39.2	0.0065	0.00052, <RDL,H	10.4	3.21	0.0236	0.0017, <RDL,H	--	<0.19	<0.19	120
11/2/11	6.66	30.40	--	0.179	0.0187, H	32.8	0.00343	0.001, <RDL,H	8.9	2.57	0.00971	0.00273, H	8	<0.19	<0.19	95
11/15/11	6.52	37.20	--	0.16	0.00524, H	33.9	0.00289	0.00065, <RDL,H	9.24	2.63	0.00977	0.0024, <RDL,H	6.6	<0.19	<0.19	8
11/21/11	6.62	17.20	--	0.113	0.0114, H	35	0.00223	0.00098, <RDL,H	9.63	2.67	0.00881	0.00448, H	8.5	<0.19	<0.19	260
11/29/11	6.53	41.40	--	0.156	0.0043, <RDL,H	33.3	0.00345	0.00065, <RDL,H	9.14	2.53	0.0117	0.00256, H	7	<0.19	<0.19	5
12/15/11	6.56	31.80	--	0.181	0.011, H	54.5	0.002, <RDL	<0.0004, H	14.7	4.29	0.00626	0.0011, <RDL,H	4.73	<0.19	<0.19	1

Notes

[1] PSD data was analyzed by two different laboratories during the project duration. The second laboratory (sample dates after Apr.22.10) did not report on the mean particle size. Full analytical reports from all PSD samples can be found in Appendix E.

"—" = no sample data

Values reported with "<RDL" indicate the target analyte was above the method detection limit but below the reporting detection limit.

Values reported with "<" indicate target analyte was not detected at reported value.

Values reported with "H" indicate the holding time was exceeded for that analyte.

Values reported with "J" indicate an estimated value for that analyte.

Table 14. Sampling Analytical Results for USFOL

Sample Date	pH	TSS (mg/L)	PSD (mean size)[1] (µm)	Total-P (mg/L)	Ortho-P (mg/L)	Hardness (mg/L)	Total Cu (mg/L)	Diss. Cu (mg/L)	Total Ca (mg/L)	Total Mg (mg/L)	Total Zn (mg/L)	Diss. Zn (mg/L)	Temp. (˚C)	TPH Diesel (mg/L)	TPH Oil (mg/L)	Fecal Coliform (cfu/ 100mls)
10/14/09	--	2.2	4.29	0.048	0.0161, H	26	0.00276	0.002, <RDL,H	7.31	1.87	0.00265	0.0024, <RDL,H	--	<0.19	<0.19	--
10/21/09	--	<1	3.92	0.015	0.00874	31.8	0.0017, <RDL	0.0016, <RDL	9.23	2.12	0.00098, <RDL	0.0014, <RDL	--	<0.19	<0.19	--
11/5/09	--	0.8, <RDL	9.35	0.0211	0.00771, H	40	0.0014, <RDL	0.0015, <RDL,H	11.1	2.95	0.0011, <RDL	0.00089, <RDL,H	--	<0.19	<0.19	--
11/18/09	6.52	<0.5	4.64	0.0176	0.00823, H	32.6	0.00596,	0.00552, H	9.16	2.35	0.0014, <RDL	0.0013, <RDL,H	9.32	<0.19	<0.19	--
12/20/09	6.43	<1	5.85	0.0213	0.00842, H	34.8	0.0017, <RDL	0.0016, <RDL,H	9.58	2.64	0.001, <RDL	0.0008, <RDL,H	2.8	<0.19	<0.19	--
1/4/10	6.47	0.5, <RDL	6.42	0.0178	0.00712, H	30.6	0.0014, <RDL	0.0015, <RDL,H	8.53	2.27	0.0018, <RDL	0.0016, <RDL,H	8.03	<0.19	<0.19	--
1/14/10	6.59	<0.5	6.71	0.0127	0.00717, H	30.5	0.0012, <RDL	0.0013, <RLD,H	8.52	2.23	0.0011, <RDL	0.0011, <RDL,H	8.4	<0.19	<0.19	--
2/11/10	6.59	<0.5	4.61	0.0088, <RDL	0.00716, H	42	0.00273	0.00247, H	11.9	2.97	0.0016, <RDL	0.0016, <RDL,H	7.1	<0.19	<0.19	--
3/3/10	6.93	<0.6	7.18	0.0113	0.00624, H	33.2	0.00207	0.00225, H	9.24	2.47	0.00093, <RDL	0.0013, <RDL,H	9.41	<0.19	<0.19	--
4/22/10	6.49	0.71, <RDL	5.62	0.0281	0.00897, H	26.6	0.00218	0.002, <RDL,H	7.52	1.9	0.00335	0.00406, H	11.4	<0.19	<0.19	--
5/19/10	6.29	2.2	--	0.0753	0.0338, H	42.6	0.003	0.00224, H	12.4	2.85	0.0025, <RDL	0.0016, <RDL,H	13.7	<0.19	<0.19	88
6/10/10	6.51	0.8, <RDL	--	0.0214	0.00723, H	32.1	0.00286	0.00214, H	9.07	2.29	0.0022, <RDL	0.0014, <RDL,H	16.2	<0.19	<0.19	14
9/17/10	6.86	<1	--	0.0341	0.0142, H	44.7	0.00445	0.0038, H	12.6	3.19	0.0023, <RDL	0.0018, <RDL,H	17.2	<0.19	<0.19	<1
11/1/10	6.65	1.1	--	0.0266	0.00752, H	35.8	0.0018, <RDL	0.0018, <RDL,H	9.95	2.65	0.00297	0.00278, H	11.4	<0.19	<0.19	77
11/8/10	6.95	<0.5	--	0.0088, <RDL	0.00649, H	44.7	0.00221	0.00225, H	12.6	3.23	0.0014, <RDL	0.0013, <RDL,H	10	<0.19	<0.19	<1
11/18/10	6.76	0.5, <RDL	--	0.0378	0.0106, H	39.5	0.0019, <RDL	0.0017, <RDL,H	10.7	3.12	0.0015, <RDL	0.0013, <RDL,H	7.8	<0.19	<0.19	5
12/7/10	6.48	0.7, <RDL	--	0.0188	0.0048, <RDL,H	69	0.001, <RDL	0.001, <RDL,H	19.6	4.87	0.0011, <RDL	0.001, <RDL,H	7.2	<0.19	<0.19	10
12/15/10	6.48	<0.5	--	0.0154	0.00886, H	35.2	0.001, <RDL	0.0011, <RDL,H	10.2	2.38	0.00072, <RDL	<0.5, H	7.3	<0.19	<0.19	6
1/12/11	6.32	<0.5	--	0.01, <RDL	0.00526, H	39.7	0.0013, <RDL	0.0011, <RDL,H	11.4	2.71	0.0011, <RDL	0.0011, <RDL,H	2.6	<0.19	<0.19	1
1/21/11	6.71	0.5, <RDL	--	0.011	0.00833, H	28.5	0.0011, <RDL	0.0011, <RDL,H	8.13	1.98	0.0015, <RDL	0.00475, H	7.1	<0.19	<0.19	14
2/7/11	6.51	0.64, <RDL	--	0.0051, <RDL	0.00725, H	36.3	0.0013, <RDL	0.0015, <RDL,H	10.4	2.5	0.00093, <RDL	0.00086, <RDL,H	7.9	<0.19	<0.19	<1

Sample Date	pH	TSS (mg/L)	PSD (mean size)[1] (µm)	Total-P (mg/L)	Ortho-P (mg/L)	Hardness (mg/L)	Total Cu (mg/L)	Diss. Cu (mg/L)	Total Ca (mg/L)	Total Mg (mg/L)	Total Zn (mg/L)	Diss. Zn (mg/L)	Temp. (˚C)	TPH Diesel (mg/L)	TPH Oil (mg/L)	Fecal Coliform (cfu/ 100mls)
3/9/11	6.73	0.6, <RDL	--	0.0106	0.00598, H	43.2	0.0015, <RDL	0.0014, <RDL,H	12.1	3.14	0.0014, <RDL	0.00082, <RDL,H	8.1	<0.19	<0.19	4
3/14/11	6.67	<0.5	--	0.0145	0.00668, H	28.9	0.0015, <RDL	0.0015, <RDL,H	8.43	1.91	0.00099, <RDL	0.0008, <RDL,H	9	<0.19	<0.19	4
4/4/11	6.77	<1	--	0.0091, <RDL	0.00698, H	37.6	0.0015, <RDL	0.0015, <RDL,H	10.8	2.61	0.0019, <RDL	0.00081, <RDL,H	7.7	<0.19	<0.19	5
4/27/11	6.79	<0.5	--	0.0261	0.0062, H	34.1	0.00246	0.00246, H	9.96	2.24	0.0014, <RDL	0.0013, <RDL,H	11.8	<0.19	<0.19	<1
5/25/11	6.03	1.1, <RDL	--	0.0533	0.0211, H	40.3	0.00288	0.0026, H	11.6	2.75	0.0021, <RDL	0.0017, <RDL,H	13.5	<0.19	<0.19	2
9/26/11	--	50	--	0.315	0.046, H	48.2	0.00424	0.0011, <RDL,H	13.2	3.7	0.0154	0.0014, <RDL,H	--	--	--	--

Notes

[1] PSD data was analyzed by two different laboratories during the duration of the project. The second laboratory (sample dates after Apr.22.10) did not report on the mean particle size. Full analytical reports from all PSD samples can be found in Appendix E.

"—" = no sample data

Values reported with "<RDL" indicate the target analyte was above the method detection limit but below the reporting detection limit.

Values reported with "<" indicate target analyte was not detected at reported value.

Values reported with "H" indicate the holding time was exceeded for that analyte.

3.2.4 Boulder Creek Lower Vault Inlet (LVIN)

For the LVIN site, TSS concentrations were below the MDL for one of the 17 samples. All other conventional, metals and nutrient concentrations were above the MDL for all of the composite samples (Table 15). Orthophosphate phosphorus concentrations were below the RDL for three samples, total copper concentrations were below the RDL for one sample, and dissolved copper concentrations were below the RDL for four samples.

There were 18 grab samples collected for diesel and lube oil analysis, and 16 grab samples collected for fecal coliform analysis. Diesel range concentrations were below the MDL for all samples and lube oil concentrations were below the MDL for 10 of the 18 samples. Concentrations for 2 of the 16 fecal coliform samples were below the MDL.

3.2.5 Boulder Creek Lower Vault Outlet (LVOL)

With the exception of orthophosphate phosphorus concentration from one sample, for the LVOL site, conventional, metals and nutrient concentrations were above the MDL for all 21 composite samples (Table 16). Orthophosphate phosphorus concentrations were also above the MDL, but below the RDL for seven samples, and dissolved copper was below the RDL for eight samples.

There were 23 grab samples collected for diesel and lube oil analysis, and 20 grab samples collected for fecal coliform analysis. Diesel range concentrations were below the MDL for all samples while lube oil concentrations were below the MDL for 17 samples. Fecal coliform grab concentrations were above the MDL for all but one sample.

3.2.6 Boulder Creek Lower Sand Filter Outlet (LSFOL)

For the Boulder Creek Lower Sand Filter Outlet site, TSS concentrations were below the MDL for six of the 17 samples and total phosphorus concentrations were below the MDL for one sample (Table 17). Otherwise, conventional, metals and nutrient concentrations were above the MDL for all composite samples. In addition, all samples were above the RDL for all but the following parameters:

- Dissolved zinc was below RDL for six samples
- TSS, total phosphorus and orthophosphate phosphorus were below the RDL for four samples
- Total copper was below the RDL for eight samples
- Dissolved copper was below the RDL for ten samples
- Total zinc was below the RDL for two samples

There were 21 grab samples collected for diesel and lube oil analysis, and 19 grab samples collected for fecal coliform analysis. Diesel range concentrations were below the MDL for all samples and lube oil concentrations were below the MDL for all but one sample. Fecal coliform concentrations were below the MDL for three samples.

Table 15. Sampling Analytical Results for LVIN

Sample Date	pH	TSS (mg/L)	PSD (mean size)[1] (µm)	Total-P (mg/L)	Ortho-P (mg/L)	Hardness (mg/L)	Total Cu (mg/L)	Diss. Cu (mg/L)	Total Ca (mg/L)	Total Mg (mg/L)	Total Zn (mg/L)	Diss. Zn (mg/L)	Temp. (˚C)	TPH Diesel (mg/L)	TPH Oil (mg/L)	Fecal Coliform (cfu/ 100mls)
1/13/10	7.19	27.1	15.54	0.0363	0.0046, <RDL,H	11.5	0.00838	0.0035 H	3.33	0.769	0.0284	0.00879 H	9.8	<0.19	0.574	--
2/24/10	7.61	24.5	18.89	0.0582	0.00565, H	20.5	0.00907	0.00429 H	6.35	1.12	0.0479	0.017 H	9.3	<0.19	<0.19	--
11/1/10	7.05	16.5	17.2	0.0543	0.0151, H	39.9	0.00673	0.00368 H	11.8	2.52	0.0328	0.0133 H	13	<0.19	0.355	300
11/30/10	6.83	32.4	17.2	0.0529	0.0039, <RDL,H	17.3	0.00743	0.00244 H	5.4	0.925	0.0327	0.00742 H	6.5	<0.19	0.542	60
12/13/10	7.57	30	--	0.046	0.00696, H	39.1	0.00713	0.00213 H	11.2	2.68	0.0239	0.005 H	8.1	<0.19	<0.19	240
12/28/10	7.37	<0.19	--	0.0204	0.0125, H	43.5	0.00373	0.00328 H	12.9	2.73	0.00706	0.00573 H	8.2	<0.19	<0.19	<1
1/13/11	6.96	26.8	--	0.0275	0.00739, H	12.2	0.00408	0.0012 <RDL,H	3.84	0.637	0.0193	0.00547 H	8.5	<0.19	<0.19	51
1/21/11	7.51	14.8	--	0.0298	0.00856, H	21.1	0.00342	0.0016 <RDL,H	6.42	1.24	0.0155	0.00543 H	8	<0.19	0.299	150
3/2/11	7.1	40	--	0.0656	0.00669, H	50.8	0.00903	0.00256 H	14.9	3.28	0.0498	0.00898 H	8.6	<0.19	0.573	1200
3/16/11	7.55	1.7	--	0.0186	0.0135, H	43.7	0.002 <RDL	0.0017 <RDL,H	13	2.71	0.0086	0.00708 H	8.5	<0.19	<0.19	7
3/29/11	7.18	10.2	--	0.0237	0.00664, H	14.2	0.00443	0.0028 H	4.35	0.802	0.02	0.00792 H	10.1	<0.19	<0.19	27
4/4/11	7.68	13.5	--	0.0259	0.0041, <RDL,H	12.2	0.00378	0.0016 <RDL,H	3.71	0.715	0.0208	0.00726 H	8.2	<0.19	<0.19	<1
4/25/11	6.88	13.7	--	0.0333	0.00657, H	9.69	0.00491	0.00234 H	3.06	0.494	0.0218	0.00774 H	10.8	<0.19	0.435	80
5/31/11	6.82	26.2	--	0.0749	0.0101, H	12.7	0.00974	0.00488 H	3.94	0.682	0.0455	0.0131 H	12.5	<0.19	0.442	1900
9/26/11	7.32	14.6	--	0.0722	0.0232, H	53.4	0.0421	0.00503 H	15.9	3.33	0.109	0.0114 H	17.6	<0.19	<0.19	5400
11/2/11	7.64	40.3	--	0.101	0.0277, H	7.1	0.0057	0.00227 H	2.22	0.378	0.0384	0.012 H	11.13	<0.19	<0.19	8
11/14/11	7.64	14.4	--	0.061	0.0147, H	24.6	0.00678	0.00352 H	7.44	1.46	0.0394	0.022 H	7.82	<0.19	<0.19	8
12/15/11	7.34	--	--	--	--	--	--	--	--	--	--	--	5.83	<0.19	0.377	260

Notes:

[1] PSD data was analyzed by two different laboratories during the project. The second laboratory (sample dates after Apr.22.10) did not report on the mean particle size. Full analytical reports from all PSD samples can be found in Appendix E.

"—" = no sample data

Values reported with "<RDL" indicate the target analyte was above the method detection limit but below the reporting detection limit.

Values reported with "<" indicate target analyte was not detected at reported value.

Values reported with "H" indicate the holding time was exceeded for that analyte.

Table 16. Sampling Analytical Results for LVOL

Sample Date	pH	TSS (mg/L)	PSD (mean size)[1] (µm)	Total-P (mg/L)	Ortho-P (mg/L)	Hardness (mg/L)	Total Cu (mg/L)	Diss. Cu (mg/L)	Total Ca (mg/L)	Total Mg (mg/L)	Total Zn (mg/L)	Diss. Zn (mg/L)	Temp. (˚C)	TPH Diesel (mg/L)	TPH Oil (mg/L)	Fecal Coliform (cfu/ 100mls)
2/11/10	7.25	2.6	5.67	0.0415	0.0136, H	44.5	0.00382	0.0027 H	14.7	1.9	0.0165	0.0127 H	8.3	<0.19	<0.19	--
3/3/10	7.21	2.36	11.77	0.043	0.0117, H	30.1	0.0029	0.00256 H	9.82	1.37	0.0125	0.0136 H	9.27	<0.19	<0.19	--
4/22/10	6.71	2.6	9.24	0.0246	0.0046, <RDL,H	11.6	0.00275	0.00204 H	3.83	0.503	0.0122	0.0103 H	11.03	<0.19	<0.19	--
5/19/10	6.14	8.12	--	0.0367	<0.006, TA, H	2550	4.01	2.93 H	721	183	1.12	1.09 H	11.5	<0.19	<0.19	<1
6/10/10	6.93	2.6	--	0.041	0.0064, H	19	0.0118	0.00621 H	6.12	0.913	0.0151	0.0118 H	13.7	<0.19	<0.19	250
9/18/10	7.42	16.4	--	0.16	0.031, H	63.5	0.0151	0.0016 <RDL,H	22.3	1.9	0.0214	0.00476 H	16.1	<0.19	<0.19	90
11/1/10	6.8	4	--	0.027	0.0032, <RDL,H	17.9	0.00417	0.0022 H	5.69	0.908	0.0133	0.0101 H	12.4	<0.19	0.236	240
11/8/10	7.04	2.2	--	0.0289	0.00643, H	19.8	0.00477	0.00259 H	6.31	0.989	0.0131	0.011 H	11.4	<0.19	<0.19	10
11/15/10	6.91	3.68	--	0.0368	0.0103, H	21.7	0.00898	0.0036 H	6.93	1.07	0.0141	0.0112 H	11.9	<0.19	0.189	7
11/18/10	6.91	2.04	--	0.0252	0.00764, H	20	0.0037	0.0025 H	6.35	1.01	0.0123	0.0106 H	11.5	<0.19	0.192	16
12/15/10	7	3.57	--	0.0236	0.00545, H	19.2	0.00339	0.0016 <RDL,H	6.01	1.02	0.0105	0.00749 H	8.6	<0.19	<0.19	360
1/12/11	6.81	6.1	--	0.0185	0.0031, <RDL,H	27.9	0.00369	0.0017 <RDL,H	9.35	1.09	0.0167	0.0114 H	4.6	<0.19	<0.19	240
1/21/11	7.06	4.5	--	0.0148	0.0039, <RDL,H	14.3	0.00226	0.0012 <RDL,H	4.71	0.619	0.0135	0.00794 H	8	<0.19	0.264	74
3/9/11	6.96	4.4	--	0.0294	0.0051, H	40	0.0056	0.00235 H	13.2	1.72	0.0182	0.0133 H	7.9	<0.19	<0.19	11
3/14/11	6.99	3.5	--	0.0279	0.00766, H	16.3	0.00308	0.0018 <RDL,H	5.19	0.817	0.0127	0.00967 H	8.4	<0.19	0.196	14
4/4/11	7.26	3.2	--	0.0216	0.0033, <RDL,H	18.2	0.00592	0.0019 <RDL,H	5.7	0.958	0.0139	0.00974 H	8.6	<0.19	<0.19	31
4/27/11	6.9	5.5	--	0.0543	0.0043, <RDL,H	21.1	0.00543	0.00315 H	7.18	0.76	0.0148	0.0104 H	10.5	<0.19	<0.19	91
5/25/11	6.41	8.8	--	0.0865	0.00878, H	26.2	0.00678	0.00361 H	8.71	1.08	0.0183	0.0109 H	11.5	<0.19	<0.19	80
11/2/11	6.88	4.6	--	0.0632	0.0279, H	15.9	0.00455	0.00227 H	5.28	0.651	0.016	0.0112 H	11.57	<0.19	<0.19	100
11/21/11	6.96	3.4	--	0.034	0.0036, <RDL,H	19.8	0.00341	0.0019 <RDL,H	6.47	0.877	0.0171	0.0137 H	8.4	<0.19	<0.19	4500
11/29/11	6.98	2.2	--	0.0553	0.00568, H	19.4	0.00259	0.0015 <RDL,H	6.19	0.962	0.0132	0.0121 H	8.8	<0.19	<0.19	390

Sample Date	pH	TSS (mg/L)	PSD (mean size)[1] (µm)	Total-P (mg/L)	Ortho-P (mg/L)	Hardness (mg/L)	Total Cu (mg/L)	Diss. Cu (mg/L)	Total Ca (mg/L)	Total Mg (mg/L)	Total Zn (mg/L)	Diss. Zn (mg/L)	Temp. (˚C)	TPH Diesel (mg/L)	TPH Oil (mg/L)	Fecal Coliform (cfu/ 100mls)
12/8/10	6.91	--	--	--	--	--	--	--	--	--	--	--	8.5	<0.19	0.224	130
10/21/12	--	--	--	--	--	--	--	--	--	--	--	--	--	<0.19	<0.19	2

Notes:

[1] PSD data was analyzed by two different laboratories during water year 2010. The second laboratory (sample dates after Apr.22.10) did not report on the mean particle size. Full analytical reports from all PSD samples can be found in Appendix E.

"—" = no sample data

Values reported with "<RDL" indicate the target analyte was above the method detection limit but below the reporting detection limit.

Values reported with "<" indicate target analyte was not detected at reported value.

Values reported with "H" indicate the holding time was exceeded for that analyte.

Table 17. Sampling Analytical Results for LSFOL.

Sample Date	pH	TSS (mg/L)	PSD (mean size)[1] (µm)	Total-P (mg/L)	Ortho-P (mg/L)	Hardness (mg/L)	Total Cu (mg/L)	Diss. Cu (mg/L)	Total Ca (mg/L)	Total Mg (mg/L)	Total Zn (mg/L)	Diss. Zn (mg/L)	Temp. (˚C)	TPH Diesel (mg/L)	TPH Oil (mg/L)	Fecal Coliform (cfu/ 100mls)
2/11/10	6.75	<0.5	4.6	0.0155	0.0113, H	--	--	--	--	--	--	--	7.9	<0.19	<0.19	--
3/3/10	6.74	<0.6	5.09	0.0136	0.00933, H	218	0.00217	0.00235 H	57.2	18.2	0.00285	0.00366 H	8.97	<0.19	<0.19	--
5/19/10	7.15	2.73	--	0.066	0.0262, H	145	0.0117	0.00782 H	42.9	9.19	0.0108	0.00896 H	11.8	<0.19	0.195	42
6/10/10	6.74	<0.9	--	0.0209	0.0065, H	35.7	0.00598	0.00475 H	10.5	2.33	0.00837	0.00566 H	14.2	<0.19	<0.19	32
9/17/10	7.04	2.12	--	0.0672	0.0355, H	181	0.00817	0.00666 H	49.4	13.9	0.0116	0.0104 H	15.2	<0.19	<0.19	22
11/1/10	6.96	1.4	--	0.0258	0.0047, <RDL,H	45.9	0.0023	0.0018 <RDL,H	13.1	3.18	0.00297	0.0024 <RDL,H	12.2	<0.19	<0.19	97
11/9/10	6.48	--	--	--	--	--	--	--	--	--	--	--	7.82	<0.19	<0.19	<1
11/16/10	6.64	--	--	--	--	--	--	--	--	--	--	--	11	<0.19	<0.19	<1
11/18/10	6.83	<0.6	--	0.012	0.00729, H	61.3	0.0018 <RDL	0.0016 <RDL,H	16.5	4.86	0.0011 <RDL	0.0011 <RDL,H	10.1	<0.19	<0.19	<1
12/7/10	6.91	0.8, <RDL	--	0.019	0.00777, H	110	0.002 <RDL	0.0017 <RDL,H	30.4	8.38	0.00435	0.00381 H	8.3	<0.19	<0.19	37
1/12/11	6.92	0.6, <RDL	--	0.0093, <RDL	0.0042, <RDL,H	42.1	0.0016 <RDL	0.0012 <RDL,H	13.1	2.3	0.00341	0.00263 H	5.3	<0.19	<0.19	55
1/21/11	7.23	1.4	--	0.0084, <RDL	0.00501, H	27	0.0016 <RDL	0.0011 <RDL,H	8.28	1.54	0.00316	0.002 <RDL,H	7.7	<0.19	<0.19	32
3/9/11	7.18	0.6, <RDL	--	0.008, <RDL	0.0055, H	84.8	0.0016 <RDL	0.0016 <RDL,H	23.7	6.19	0.00284	0.00277 H	7.8	<0.19	<0.19	7
3/14/11	6.93	<1	--	0.0065, <RDL	0.0049, <RDL,H	30.7	0.0016 <RDL	0.0016 <RDL,H	9.51	1.69	0.00289	0.0024 <RDL,H	8.2	<0.19	<0.19	5
4/4/11	7.19	0.5, <RDL	--	<0.005	0.0035, <RDL,H	30.8	0.002 <RDL	0.0018 <RDL,H	9.47	1.74	0.00318	0.00329 H	8.7	<0.19	<0.19	5
5/25/11	6.39	2.14	--	0.029	0.0145, H	82.7	0.0031	0.0028 H	22.3	6.59	0.00311	0.00274 H	11.3	<0.19	<0.19	1
9/26/11	6.41	--	--	--	--	--	--	--	--	--	--	--	12.3	<0.19	<0.19	77
10/21/11	--	1.4	--	0.0264	0.0117, H	143	0.0015 <RDL	0.0014 <RDL,H	37.2	12.3	0.00286	0.0022 <RDL,H		<0.19	<0.19	7
11/2/11	6.96	2.7	--	0.0521	0.022, H	83.5	0.00397	0.00319 H	23.1	6.26	0.00401	0.00334 H	10.97	<0.19	<0.19	23
11/21/11	6.97	<0.5	--	0.0146	0.00507, H	26.4	0.00201	0.0017 <RDL,H	8.36	1.34	0.0017 <RDL	0.0013 <RDL,H	8.7	<0.19	<0.19	450
12/15/11	6.62	--	--	--	--	--	--	--	--	--	--	--	14.42	<0.19	<0.19	1

Notes:

[1] PSD data was analyzed by two different laboratories during the project. The second laboratory (sample dates after Apr.22.10) did not report on the mean particle size. Full analytical reports from all PSD samples can be found in Appendix E.
"—" = no sample data
Values reported with "<RDL" indicate the target analyte was above the method detection limit but below the reporting detection limit.
Values reported with "<" indicate target analyte was not detected at reported value.
Values reported with "H" indicate the holding time was exceeded for that analyte.

3.2.7 Field QA/QC Results

Throughout the sampling program dissolved zinc and dissolved copper field filtration blanks were collected during nineteen sampling events. Orthophosphate phosphorus field filtration blank samples were collected during each sampling event. Results for all samples were below the RDL for all three analytes. With three exceptions, all field filtration blanks concentrations were below the MDL for all three analytes.

The field filtration blank collected on May 20, 2010 (associated with samples with a collection date of May 19, 2010) had a dissolved zinc concentration of 0.83 µg/L. The laboratory information management system (LIMS) MDL for dissolved zinc for this sample was 0.5 µg/L while the LIMS RDL was 2.5 µg/L. Concentrations of dissolved zinc in the associated stormwater samples were as follows: UPOL = 2.67 ug/L; USFOL = 1.6 ug/L; LVOL = 1090 ug/L; and LSFOL = 8.96 ug/L. Since the result from the associated samples at UPOL and USFOL were less than ten times the concentration in the field blank, those samples are considered to be affected by contamination. Since the results from the associated samples at LVOL and LSFOL were greater than ten times the concentration in the field blank, the results from those samples are not considered to be affected by contamination.

The field filtration blank collected on November 16, 2010 (associated with the LVOL sample collected on November 15, 2010) had a dissolved copper concentration of 1.8 µg/L. The LIMS MDL for dissolved copper for this sample was 0.4 µg/L while the LIMS RDL was 2 µg/L. The dissolved copper concentration in the associated LVOL sample was reported at 3.6 µg/L. Since the results from the sample collected at LVOL was less than ten times the concentration in the field filtration blank, the sample is considered to be affected by contamination.

The field filtration blank collected on November 22, 2011 (associated with samples with a collection date of November 21, 2010) had an orthophosphate phosphorus concentration of 0.0038 mg/L. The LIMS MDL for orthophosphate phosphorus for this sample was 0.002 mg/L while the LIMS RDL was 0.005 mg/L. Concentrations of orthophosphate phosphorus in the associated stormwater samples were as follows: UPIN = 0.0361 mg/L; UPOL = 0.0114 mg/L; LVOL = 0.0036 mg/L; and LSFOL = 0.00507 mg/L. Since the results from the associated samples were less than ten times the concentration in the field blank the samples are considered to be affected by contamination.

In addition, the field filtration blank collected on March 4, 2010 did not meet the analytical holding time for orthophosphate phosphorus. The results were therefore qualified.

3.3 Sediment Sampling

Sediment samples were collected annually from each BMP that had sediment accumulation. In 2010, samples were collected on June 28 from the LVOL and LSFOL sites and on June 29 from the UPOL and LVIN sites. In 2011 samples were collected from the UPIN, UPOL, LVIN, LVOL, and LSFOL sites on July 20. No samples were collected at the UPIN site in 2010, or at the USFOL site in 2010 or 2011, as there was no sediment accumulated at these sites. Results for grain size analysis for all five sizes are presented in Figure 4. As shown on the graph, the detention inlet sites (UPIN, LVIN) sediment samples were predominantly sand, while the detention outlet/sand filter inlet sites (UPOL, LVOL) and the sand filter inlet site (LSFOL) were composed of a mixture of clay, silt, sand and gravel.

The analytical results of the sediment samples collected from the five locations are summarized in Table 18. The analytical laboratory report is included with the stormwater laboratory reports which are provided electronically on an included cd as Appendix E.

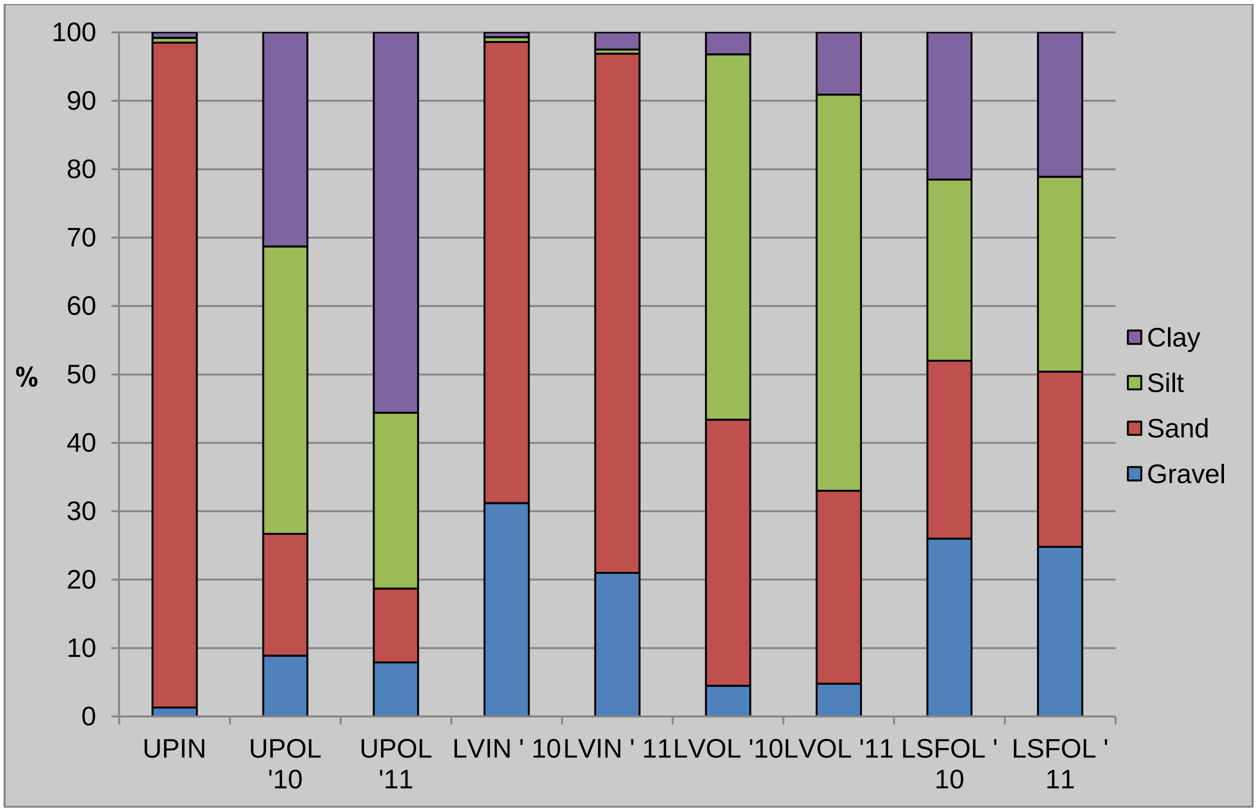

Figure 4. Grain size distribution for sediment samples.

Table 18. Analytical sediment data from BMP monitoring sites (wet weight basis).

Analyte	Units	UPIN	UPOL		LVIN		LVOL		LSFOL	
		7/20/11	6/29/10	7/20/11	6/29/10	7/20/11	6/28/10	7/20/11	6/28/10	7/20/11
Cadmium, Total	mg/Kg	<0.1	<0.1	0.1,<RDL	<0.1	<0.1	0.24,<RDL	0.24,<RDL	<0.1	<0.1
Copper, Total	mg/Kg	12.1	9.23	13.5	8.44,J	12.9	33.4	35.3	17.1	24.1
Lead, Total	mg/Kg	2.4,<RDL	2.8,<RDL	4.4,<RDL	2.7,<RDL	5.12	48.6	51.3	2.9,<RDL	5.42
Zinc, Total	mg/Kg	43.4	32.5	46.6	31.3	51.1	262	248	31.9	49.9
Phosphorus, Total	mg/Kg	320	446	592	253,J	256	364	386	333	402
Total Solids	%	77.3	13.5	10.3	81.7	77	31.3	31.5	58.1	40.7
Total Volatile Solids	%	1.12	2.89	2.23	0.859	2.07	7.76	7.66	1.65	2.5
Gravel	%	1.4,<RDL,J	8.9	7.9,<RDL	35.6	21.5	4.5	3.8	25.4	24.6
< -2 Phi Gravel	%	0.5,<RDL	6.4,<RDL	3.1,<RDL	8.9	4.9	2.4,<RDL	1.3,<RDL	19.8	19.9
(-1) - (-2) Phi Gravel	%	<0.14	1.1,<RDL	1.7,<RDL	4.9	1.5	0.6,<RDL	1.5,<RDL	1.7,<RDL	2.6
(-1) - 0 Phi Gravel	%	0.9,<RDL	1.4,<RDL	3,<RDL	21.9	15.1	1.5,<RDL	1.1,<RDL	3.9	2,<RDL
Sand	%	97.5	20.2	9.5,<RDL	72.5	76.1	40.9	25.2	25.2	25.4
0-1 Phi Sand	%	14.2	3.1,<RDL	3.2,<RDL	30.2	39.2	2.6,<RDL	1.7,<RDL	3.7	2.5
1-2 Phi Sand	%	52.6	1.4,<RDL	1,<RDL	30.4	25.4	3.5	2.4,<RDL	3.7	3.5
2-3 Phi Sand	%	25.6	2.3,<RDL	1.4,<RDL	9.2	8.6	24.2	3.5,<RDL	6.3	4.3
3-4 Phi Sand	%	4.6	8.8	1.9,<RDL	1.9	2.4	6.1	4.8	8.9	10.3
4-5 Phi Sand	%	0.6,<RDL	4.7,<RDL	1.9,<RDL	0.8,<RDL	0.6,<RDL	4.6	12.7	2.6	4.9
Silt	%	0.7,<RDL	43.6	23.7	<0.67	<0.63	55.4	52.6	26	28.3
5-6 Phi Silt	%	0.7,<RDL	25.5	9.5,<RDL	<0.67	<0.63	30.1	29	5.4	7.4
6-7 Phi Silt	%	<0.7	<3.6	<4.7	<0.67	<0.63	11.1	10.9	6.5	6.2
7-8 Phi Silt	%	<0.7	7.3,<RDL	<4.7	<0.67	<0.63	12.7	10.9	8.7	9.8
8-9 Phi Silt	%	<0.7	10.9	9.5,<RDL	<0.67	<0.63	1.6,<RDL	1.8,<RDL	5.4	4.9
Clay	%	0.7,<RDL	32.7	52	<0.67	2.5	3.2,<RDL	9.1	20.6	20.9
9-10 Phi Clay	%	<0.7	14.5	23.7	<0.67	0.6,<RDL	1.6,<RDL	1.8,<RDL	8.7	7.4
>10 Phi Clay	%	0.7,<RDL	18.2	28.4	<0.67	1.9	1.6,<RDL	7.3	11.9	13.5
Fines	%	1.4,<RDL	76.4	75.7	<0.67	2.5	58.5	61.7	46.6	49.2

Notes:

Values reported with "<RDL" indicate the target analyte was above the method detection limit but below the reporting detection limit.
Values reported with "<" indicate target analyte was not detected at reported value.
Values reported with "J" indicate an estimated value for that analyte.

3.4 Operation and Maintenance

Inspections and data showed that flow volumes were not reaching the lower sand filter base from the vault which was getting significant flow during storms. Cracks and sealant problems were discovered in the vault where a pipe leads into the sand filter. The exit pipe junction from the settling vault structure was sealed and repaired to prevent leakage from the settling vault to ensure flow continuing through the pipe into the sand filter. The flow-control orifice pipe from the settling vault structure leading to the sand filter was inspected and cleared of obstruction to ensure clear flow into the sand filter.

The sand filter and vault have been inspected annually, and these inspections looked at facility appearance, apparent function, and sediment accumulation. It was determined that the facility needed maintenance and the owner had the facility and drainage system cleaned. We do not have maintenance and operations cost for the repairs to the facility, however the maintenance costs would be in the range of those which are representative of maintenance costs of a BMP or facility of similar type and construction. The annual inspections did not record the depth of sediment accumulation as maintenance standards only call for an assessment to see if the depth facility has been reduced by more than 10%. This assessment of fullness is completed by personnel during the inspection and if the standard is exceeded, maintenance of the facility is scheduled.

4.0. QUALITY ASSURANCE/QUALITY CONTROL REPORT

Data usability was assessed through various quality assurance assessments. Laboratory analyses were assessed according to the QAPP guidelines. Data were reviewed and compared to associated methods, reporting limits, control limits, hold times, and sample blanks. Very few analytical data did not meet project guidelines. The data that did not meet guidelines were flagged with data qualifiers. A data quality assurance quality control report for the stormwater composite samples, stormwater grab samples, and sediment samples is included as Appendix F.

Sample collection parameters and flow measurement data were also assessed for quality according to QAPP guidelines. During this assessment, hydraulic data collected from the pre-settling facilities and sand filters possibly indicated that flow through the systems was much slower than hydraulic monitoring equipment can accurately measure. Additionally, because the pre-settling facilities and sand filters retain water for longer than 24 hours, it has been difficult to predict flows at any given point regardless of current rainfall. As such, field crews had difficulty collecting samples according to the TAPE guideline for collecting 75% of water flowing through a BMP structure during the randomly selected 24 hour sampling period. Since the collected data met all other quality goals, a statistical assessment of the data was conducted to determine the usability of the data.

Data were separated according to whether they met the TAPE sample collection guideline for collecting 75% of the 24 hour flow or not. The data sets were then evaluated by testing the null hypothesis that there is no statistically significant difference between the means of the data that met sample collection guidelines and the data that did not. The statistical analysis showed that there were no significant differences at the 95% confidence interval between the data that met the 75% flow for the 24 hour period guideline and the samples that did not meet this guideline.

To statistically test the null hypothesis, the data were first tested using the Shapiro-Wilk test for normality. Using this test, the data were determined to be non-normal, which is typical of environmental data. Because the data were determined to be non-normal, a non-parametric statistical test, the Mann-Whitney test was used. The Mann-Whitney test is used to evaluate the significance between two means with unequal sample sizes. This test does not rely on a normal distribution of the data, but uses the rank-order of the data being tested. The p value of all the tests was greater than the 0.05 confidence interval (see Table 19). Since there were no significant differences between the data that met the 75% guideline and the data that did not, these data were determined to be usable for BMP efficiency calculations.

Table 19. Similarity Analysis Results Mann-Whitney Test

LVIN and UPIN pooled	LVOL and UPOL pooled	LSFOL and USFOL pooled
Dissolved Copper	Dissolved Copper	Dissolved Copper
met = 11 did not = 29	met = 20 did not = 33	met = 11 did not = 32
p = .456	p = .166	p = .737
no significant difference at 95%	no significant difference at 95%	no significant difference at 95%

confidence	confidence	confidence
LVIN and UPIN pooled	LVOL and UPOL pooled	LSFOL and USFOL pooled
Total Copper	Total Copper	Total Copper
met = 11 did not = 29	met = 20 did not = 33	met = 11 did not = 32
p = .456	p = .791	p = .611
no significant difference at 95% confidence	no significant difference at 95% confidence	no significant difference at 95% confidence
LVIN and UPIN pooled	LVOL and UPOL pooled	LSFOL and USFOL pooled
Orthophosphate	Orthophosphate	Orthophosphate
met = 11 did not = 29	met = 20 did not = 33	met = 11 did not = 32
p = .456	p = .458	p = .454
no significant difference at 95% confidence	no significant difference at 95% confidence	no significant difference at 95% confidence
LVIN and UPIN pooled	LVOL and UPOL pooled	LSFOL and USFOL pooled
Total Phosphorus	Total Phosphorus	Total Phosphorus
met = 11 did not = 29	met = 20 did not = 33	met = 11 did not = 32
p = .457	p = .461	p = .454
no significant difference at 95% confidence	no significant difference at 95% confidence	no significant difference at 95% confidence
LVIN and UPIN pooled	LVOL and UPOL pooled	LSFOL and USFOL pooled
Dissolved Zinc	Dissolved Zinc	Dissolved Zinc
met = 11 did not = 29	met = 20 did not = 33	met = 11 did not = 32
p = .457	p = .459	p = .445
no significant difference at 95% confidence	no significant difference at 95% confidence	no significant difference at 95% confidence
LVIN and UPIN pooled	LVOL and UPOL pooled	LSFOL and USFOL pooled
Total Zinc	Total Zinc	Total Zinc
met = 11 did not = 29	met = 20 did not = 33	met = 11 did not = 32
p = .457	p = .459	p = .362
no significant difference at 95% confidence	no significant difference at 95% confidence	no significant difference at 95% confidence

5.0. PERFORMANCE DATA ANALYSIS PROCEDURES AND RESULTS

This section summarizes the analysis procedures and water quality data collected to evaluate the pre-settling detention basin BMP (detention pond and detention vault) and the large sand filter BMP. The detention times of the BMPs evaluated in this study are considered long detention BMPs. The sampling methodology followed protocols outlined the TAPE modification for long detention BMPs (Ecology, 2008b). The data evaluation methodologies outlined in this section also follow protocols outlined in the TAPE modification for long detention BMPs. Data evaluation included:

- Testing for normal distribution
- Calculating the concentration based treatment efficiency
- Testing to determine if the effluent concentration is significantly different from the influent concentration.
- Calculating the load based treatment efficiency
- Calculating the confidence interval associated with the concentration based treatment efficiency
- Creating scatter plots
- Creating probability plots

5.1 Data Analysis Procedures

The pre-settling detention basin BMP is designed for Basic (total suspended solids) and the large sand filter BMP is designed for Basic, Enhanced (dissolved copper and zinc) and Phosphorus (total phosphorus) runoff treatment objectives. Samples were analyzed for additional parameters, including particle size distribution, cadmium, magnesium, fecal coliform and total petroleum hydrocarbons. However, only parameters specific to the basic, enhanced, and phosphorus removal treatment goals were included in the analysis and are discussed in this section.

To strengthen the statistical significance and meet the 35 sample event criterion, data from the similar BMP types were pooled prior to performing the statistical analysis and evaluating the performance of the BMP. As stated in TAPE, data from similar BMP types can be pooled if the drainage areas for the individual BMPs are of similar size and land use and the pollutant concentration variabilities are reasonably comparable. The drainage areas for the Boulder Creek Upper and Boulder Creek Lower facilities are similar in size and land use. An F-test is generally used to compare the variability between two datasets; however this test requires datasets to be normally distributed. For this project, the pollutant concentrations for the majority of the parameters were not normally distributed therefore the F-test could not be used. To examine variability, influent and effluent data from the two pre-settling detention basins (Detention) and from the two large sand filters (Sand Filter) were visually compared using scatterplots. The graphs showed a large amount of overlap in the concentrations between the two sites and data variability was considered reasonably comparable.

Analytical results that were below the method detection limit for any parameter were assigned a value equal to ½ of the method detection limit. For results that were above the method detection limit the value used was the value reported by the analytical laboratory.

5.1.1 Testing for Normal Distribution

Pooled data from the Detention inlet, Detention outlet (which is also the Sand Filter inlet) and Sand Filter outlet were tested using Shapiro-Wilk to determine if the data were normally distributed. The test revealed that none of the datasets were normally distributed, so the test was run again using log transformed data. The test using the log transformed data revealed the following datasets to be normally distributed:

- Detention inlet: TSS, orthophosphate phosphorus, total and dissolved copper, total and dissolved zinc
- Detention outlet/Sand Filter inlet: orthophosphate phosphorus
- Sand Filter outlet: total phosphorus

The remaining parameters were not found to be normally distributed using the log transformed data.

A final test was run after removing any outliers (concentrations outside of the 5 to 95 percent range were considered outliers) from the non-normally distributed datasets. Removing the outliers revealed the following additional parameters to be normally distributed:

- Detention outlet/Sand Filter inlet: Total and dissolved copper

The remaining parameters that were not revealed to be normally distributed even after removing outliers were deemed to have a non-normal distribution.

5.1.2 Concentration Based Treatment Efficiency

Concentration based treatment efficiency was calculated following procedures outlined in Method #1 of the TAPE modification for long detention BMPs (Ecology, 2008b).

Method #1: Treatment Efficiency – Concentration Based (TECB)

$$TECB = \frac{(AvgC_{in} - AvgC_{eff})}{AvgC_{in}}$$

Where:

$AvgC_{in}$ = average influent pollutant concentration from sampled events
$AvgC_{eff}$ = average effluent pollutant concentration from sampled events

After calculating the concentration based treatment efficiency, mean results for each parameter were tested to check if the difference between the influent and effluent concentrations was statistically significant. For any parameter where both the influent and effluent results were deemed normally distributed (as determined in Section 5.1.1), a one-tailed t-test was used to test for statistical significance. For parameters where the influent and/or the effluent results were deemed as having a non-normal distribution, a Mann-Whitney test was used.

Lastly, an online calculator (DSS Research, 2008), which TAPE recommends, was used to calculate the statistical power.

5.1.3 Load Based Treatment Efficiency

Load based treatment efficiency was calculated following procedures outlined in the TAPE modification for long detention BMPs (Ecology, 2008b). Since the detention pond and sand filters are lined and did not show significant water gains or losses, the load based treatment efficiency calculation followed Method 2a. Prior to performing the calculations the influent flows were normalized to the effluent flows using the ratio: (total influent flow volume)/(total effluent flow volume).

Method 2a: Treatment Efficiency – Load Based (TELB)

$$TELB = \frac{\left[\sum_{i=1}^{n}\left(C_{i,in} * V_i\right) - \sum_{i=1}^{n}\left(C_{i,eff} * V_i\right)\right]}{\sum_{i=1}^{n}\left(C_{i,in} * V_i\right)}$$

Where:

$C_{i,in}$ = influent pollutant concentration for sample event *i*
V_i = volume of sample event *i*
$C_{i,eff}$ = effluent pollutant concentration for sample event *i*
n = number of sample events

5.2 Pre-Settling Detention Basin BMP Analysis Results

There were a total of 40 influent and 53 effluent samples collected at the pre-settling detention basins. Eleven of the influent sample events and 20 of the effluent sample events met the TAPE guidelines, as described in Section 3.1. As outlined in Section 5.1.1, for some parameters outlier data points were not included in the analysis if removing them resulted in the dataset being normally distributed. For the influent and effluent Detention samples, outliers were removed from the orthophosphate phosphorus, total copper, and dissolved copper datasets prior to performing the statistical analysis.

A single outlier was also removed from the Detention effluent total zinc and dissolved zinc datasets. During the sample event on May 19, 2010 the dissolved zinc concentration was 1.09 mg/L and total zinc concentrations was 1.12 mg/L. These concentrations were more than 45 times greater than the next highest concentration, and more than 148 times greater than the median concentration. It was decided that these data points were not representative of site conditions and they were therefore removed from the dataset prior to performing the statistical analysis.

In addition, during one influent sample event and two effluent sample events equipment errors caused a loss of flow data. As a result, data from these events were not included in the load based pollutant removal efficiency calculations.

Summary statistics for the load based pollutant removal efficiencies and the concentration based pollutant removal efficiencies are presented in Table 19 and Table 20, respectively. Load based pollutant removals ranged from 74 percent reduction in total zinc to a 10 percent reduction in total phosphorus. Concentration based pollutant removals ranged from a 63 percent reduction in total zinc to a -15 percent reduction in total phosphorus. More details about each parameter are provided in the following sections.

Table 20. Summary of load based pollutant removal efficiencies for the Pre-Settling Detention Basins

Parameter	Normalized Inlet Load (lbs)	Normalized Detention Outlet Load (lbs)	Percent Reduction
TSS	382.17	124.12	68%
Total Phosphorus	1.2743	1.1450	10%
OrthoPhosphate Phosphorus	0.3647	0.2923	20%
Total Copper	0.0839	0.0357	57%
Dissolved Copper	0.0311	0.0229	27%
Total Zinc	0.4306	0.1140	74%
Dissolved Zinc	0.1382	0.0772	44%

Table 20. Summary of concentration based pollutant removal efficiencies for the Pre-Settling Detention Basins

Parameter	Influent				Effluent				Percent Reduction	Statistically Significant at α=0.10[1] (Y/N)	Statistical Power
	Mean Concentration (mg/L)	COV (%)	95% Confidence Interval (mg/L)		Mean Concentration (mg/L)	COV (%)	95% Confidence Interval (mg/L)				
TSS	17.23154	84	9.12439	17.5108	8.98922	157	3.99	6.54	48%	Y	85.8%
Total Phosphorus	0.05722	76	0.04033	0.05986	0.06579	96	0.04119	0.05982	-15%	N	18.9%
OrthoPhosphate Phosphorus	0.01603	80	0.10126	0.01581	0.01179	96	0.00753	0.01096	26%	Y	49.2%
Total Copper	0.00540	121	0.00317	0.00518	0.00302	74	0.00208	0.00296	44%	Y	69.9%
Dissolved Copper	0.00215	57	0.00152	0.00225	0.00153	52	0.00121	0.00162	29%	Y	85.6%
Total Zinc	0.02361	83	0.01503	0.02374	0.00877	67	0.00586	0.01024	63%	Y	99.8%
Dissolved Zinc	0.00817	47	0.00654	0.00850	0.00552	74	0.00349	0.00646	33%	Y	93.2%

[1]As suggested in TAPE Appendix D, for all parameters except TSS statistical significance was evaluated at an α=0.10. For TSS statistical significance was evaluated at an α=0.05.

5.2.1 Total Suspended Solids

Based on the data collected at the pre-settling detention basin BMPs, influent TSS concentrations ranged from not being detected (less than 0.19 mg/L) to 72.3 mg/L, with a median value of 13.8 mg/L (Table 21). Across the range of events sampled at the outlet of the BMP, effluent concentrations ranged from 1.6 mg/L to 85.7 mg/l, with a median value of 4.4 mg/L. As shown in Table 19, the concentration based pollutant removal calculations showed a 48 percent reduction in TSS.

The total normalized TSS loads for the detention influent site was 382.17 lbs (Table 19), while the effluent total normalized load was 124.12 lbs. The load based pollutant removal efficiency calculation showed a 68 percent reduction in TSS.

A scatter plot of influent and effluent concentrations is presented in Figure 5. At first glance influent and effluent concentrations appear to be similar. However effluent concentrations are clustered below 5 mg/L while influent concentrations are more clustered between 5 to 20 mg/L. Figure 6 indicates that effluent generally has a lower probability for a given concentration than the influent across most of the range of concentrations, except at the very low and high concentrations. Results from a 1-tailed Mann-Whitney[1] test that was applied to TSS data confirmed the observed decrease in effluent concentrations to influent concentration was statistically significant ($p<0.0001$).

Table 21. Minimum, median, and maximum TSS concentrations from influent and effluent samples collected at the Pre-Settling Detention Basin BMPs.

	Influent Concentration (mg/L) (n=39)	Effluent Concentration (mg/L) (n=51)
Minimum	<0.19	1.6
Median	13.8	4.4
Max	72.3	85.7

[1] For parameters with influent and effluent datasets that were deemed as having a normal distribution, a t-test was used to test for statistical significance. For parameters with influent and/or effluent datasets that were deemed as having a non-normal distribution, a Mann-Whitney test was used to test for statistical significance.

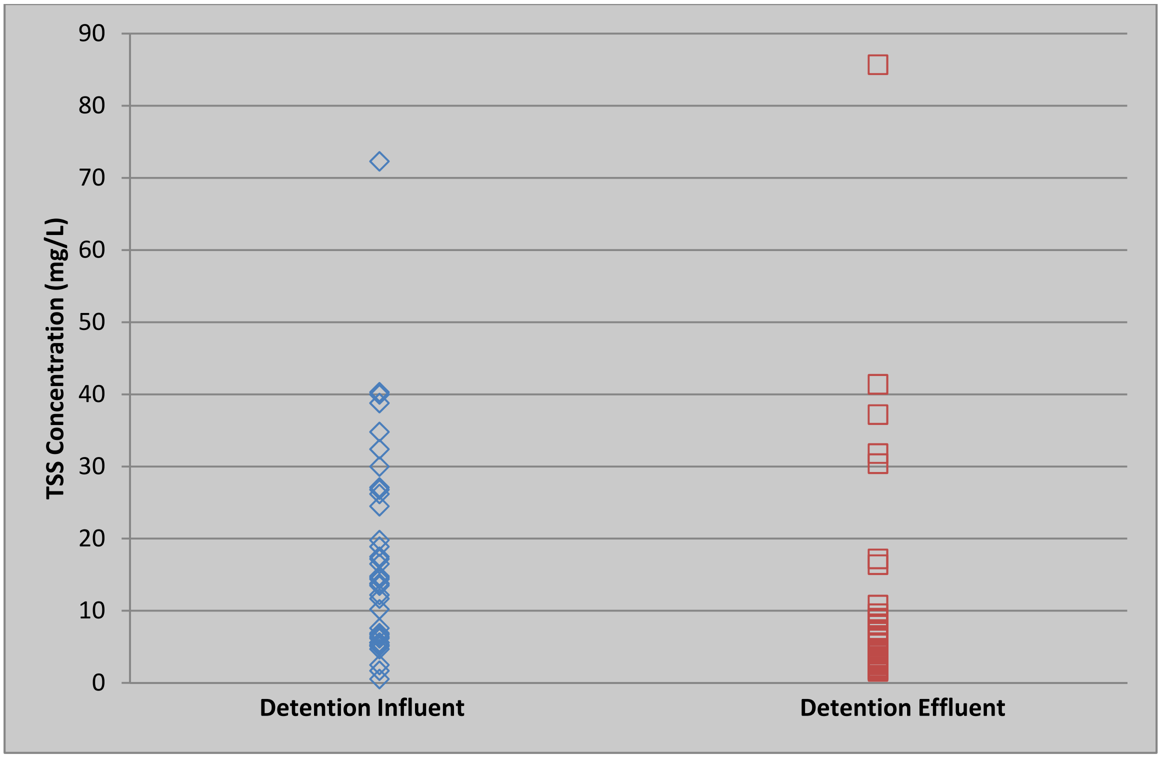

Figure 5. Scatter plot for influent and effluent TSS concentrations collected at the Pre-Settling Detention Basin BMPs.

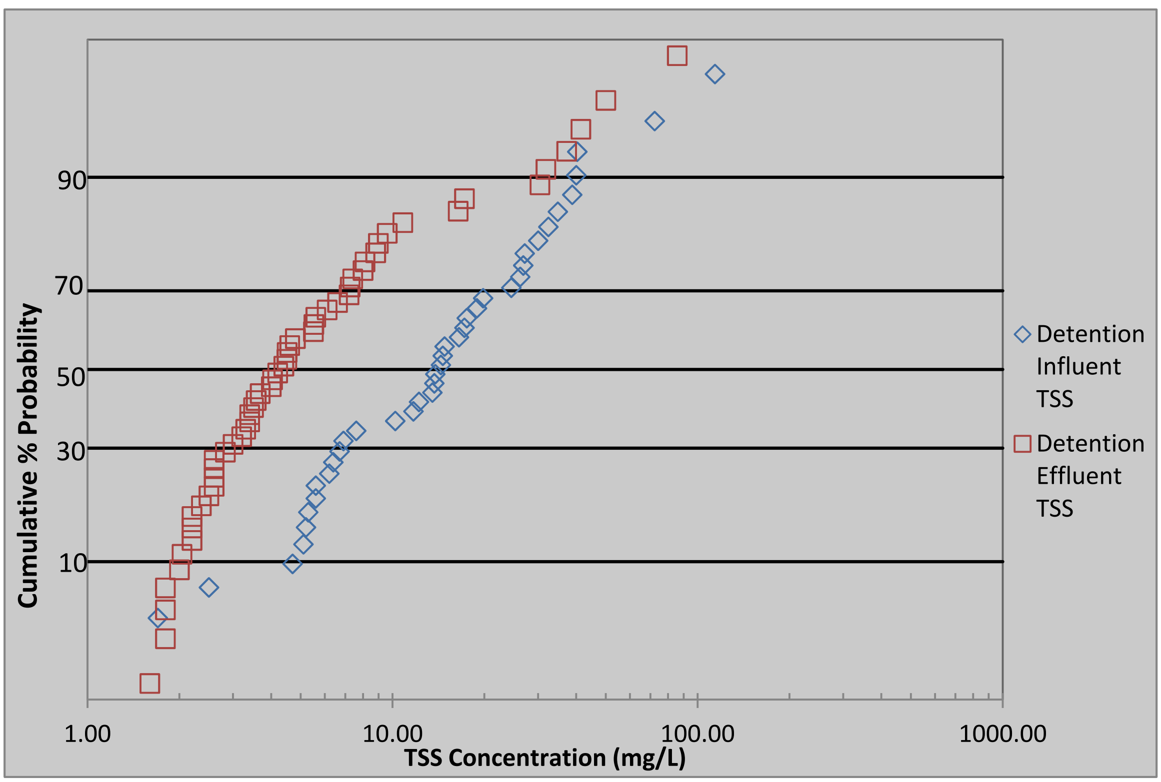

Figure 6. Probability plot for influent and effluent TSS concentrations collected at the Pre-Settling Detention Basin BMPs.

5.2.2 Total Phosphorus

Based on the data collected from the detention sites, influent total phosphorus concentrations ranged 0.0186 mg/L to 0.244 mg/L, with a median value of 0.0420 mg/L (Table 22). Across the range of events sampled at the outlet of the BMP, effluent concentrations ranged from 0.0148 mg/L to 0.383 mg/l, with a median value of 0.0459 mg/L. As shown in Table 20, the mean effluent concentration was higher than the mean influent concentration, resulting in a negative percent reduction (-15 percent).

The total normalized total phosphorus loads for the detention influent site was 1.2743 lbs. while the effluent total normalized load was 1.145 lbs. The load based pollutant removal efficiency calculation showed a 10 percent reduction in total phosphorus (Table 19). The negative concentration based pollutant reduction and the positive load based pollutant reduction is due to higher effluent concentrations of total phosphorus during sample events with lower total flow volume.

A scatter plot, presented in Figure 7, generally shows a similar range of influent and effluent total phosphorus concentrations. The probability plot for total phosphorus (Figure 8) indicates the influent and effluent probabilities are very similar across the range of concentrations. Results from a 1-tailed Mann-Whitney test that was applied to total phosphorus data confirmed that the difference in the influent and effluent concentrations was not statistically significant (p=0.4321).

Table 22. Minimum, median, and maximum Total Phosphorus concentrations from influent and effluent samples collected at the Pre-Settling Detention Basin BMPs.

	Influent Concentration (mg/L) (n=39)	Effluent Concentration (mg/L) (n=51)
Minimum	0.0186	0.0148
Median	0.0420	0.0459
Max	0.244	0.383

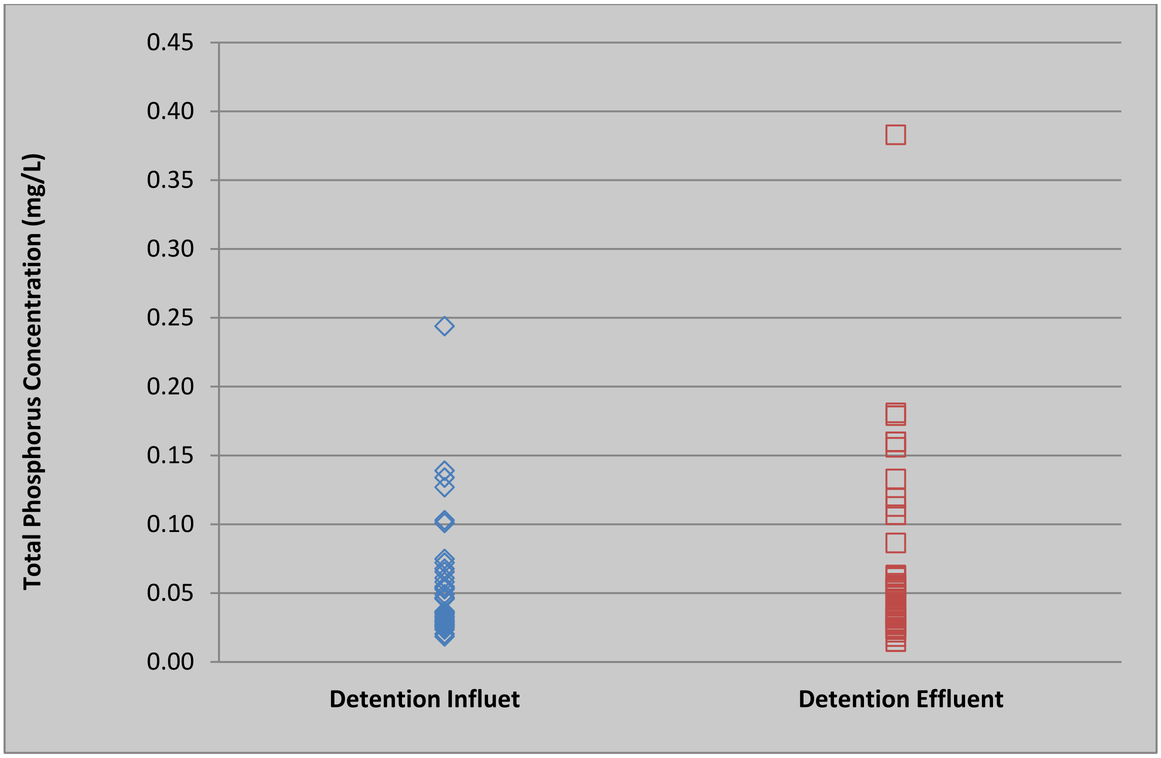

Figure 7. Scatter plot for influent and effluent Total Phosphorus concentrations collected at the Pre-Settling Detention Basin BMPs.

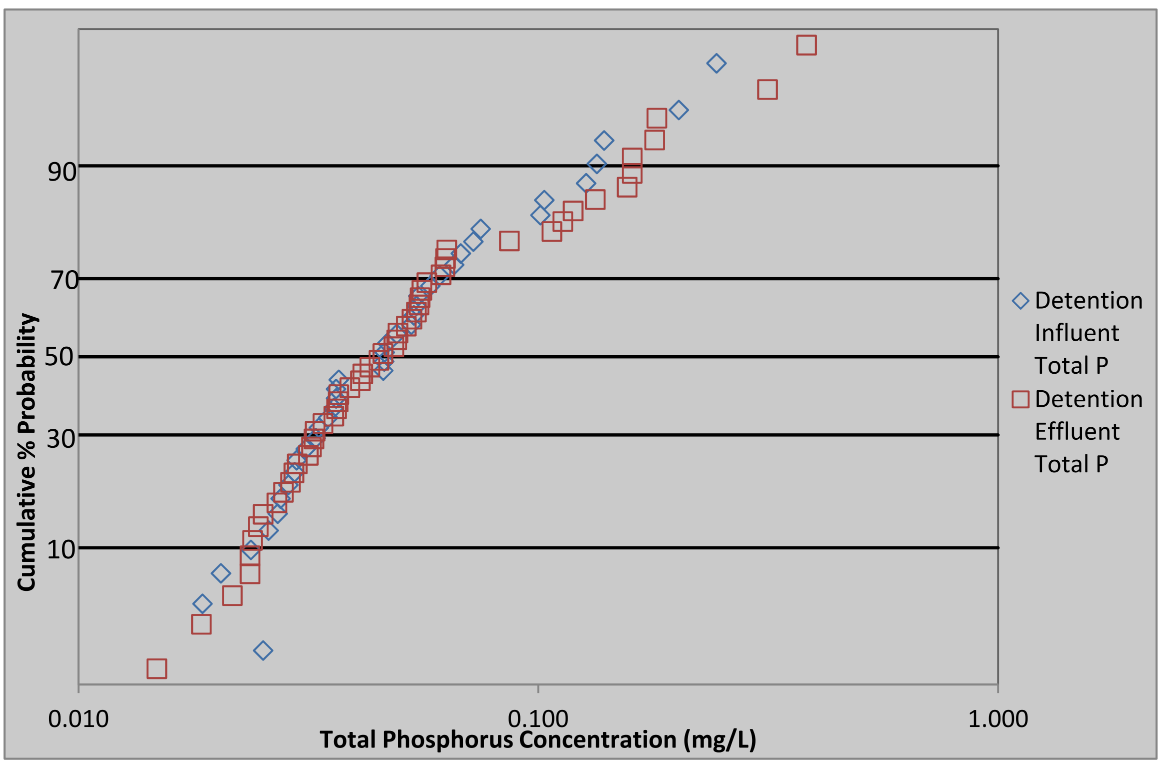

Figure 8. Probability plot for influent and effluent Total Phosphorus concentrations collected at the Pre-Settling Detention Basin BMPs.

5.2.3 Orthophosphate Phosphorus

Based on the data collected from events at the detention sites, influent orthophosphate phosphorus concentrations ranged 0.0039 mg/L to 0.0585 mg/L, with a median value of 0.01255 mg/L (Table 23). Across the range of events sampled at the outlet of the detention BMP, effluent concentrations ranged from a non-detect (less than 0.006 mg/L) to 0.0637 mg/l, with a median value of 0.00878 mg/L. As shown in Table 20, mean orthophosphate phosphorus effluent concentrations are lower than mean influent concentrations, with a concentration based pollutant removal of 26 percent.

The total normalized orthophosphate phosphorus loads for the detention influent site was 0.3647 lbs. while the effluent total normalized load was 0.2923 lbs. The load based pollutant removal efficiency calculation showed a 20 percent reduction in orthophosphate phosphorus (Table 19).

A scatter plot of influent and effluent concentrations is presented in Figure 9. At first glance influent and effluent concentrations appear to be similar. However effluent concentrations are clustered below 0.01 mg/L, with more than 20 percent of the effluent samples falling below the reporting detection limit. The cumulative percent probability plot for orthophosphate phosphorus (Figure 10) indicates that effluent has a lower probability for a given concentration than the influent across most of the range of concentrations, except at the very high concentrations. Results from a 1-tailed t-test that was applied to orthophosphate phosphorus data confirmed the observed decrease in effluent concentrations to influent concentration was statistically significant (p=0.0112).

Table 23. Minimum, median, and maximum Orthophosphate Phosphorus concentrations from influent and effluent samples collected at the Pre-Settling Detention Basin BMPs.

	Influent Concentration (mg/L) (n=39)	Effluent Concentration (mg/L) (n=51)
Minimum	0.0039	<0.006
Median	0.01255	0.00878
Max	0.0585	0.0637

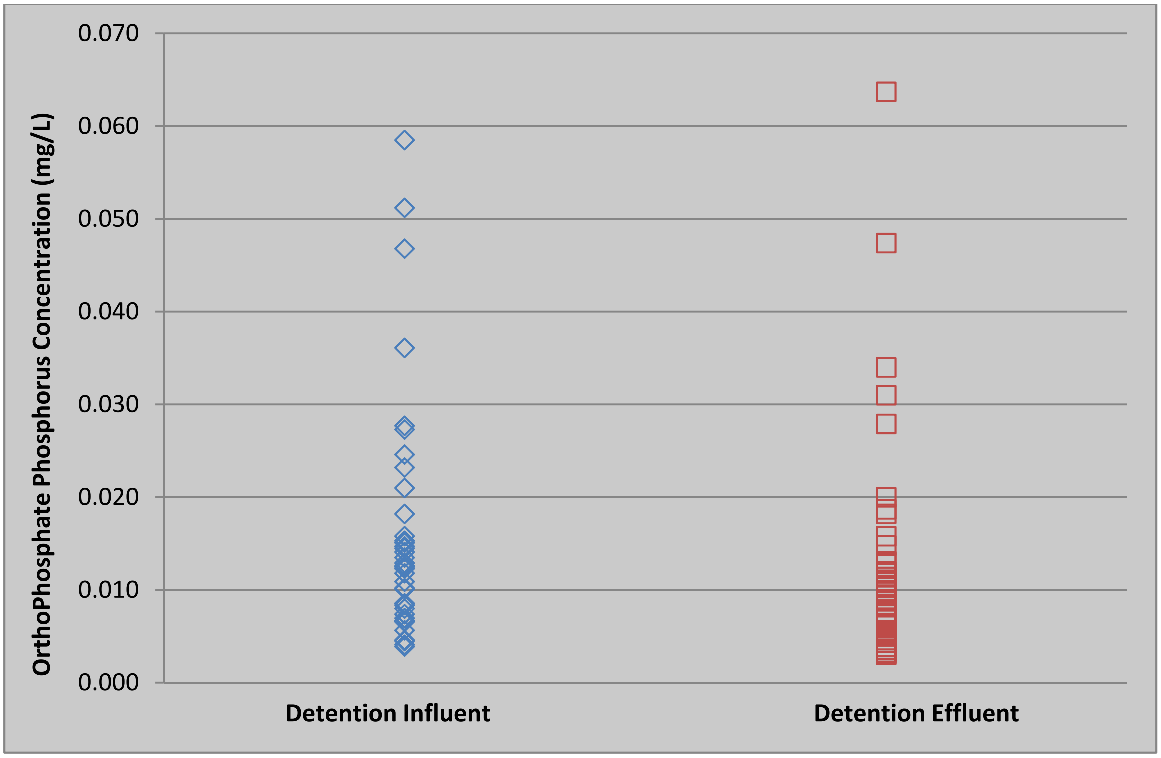

Figure 9. Scatter plot for influent and effluent Orthophosphate Phosphorus concentrations collected at the Pre-Settling Detention Basin BMPs.

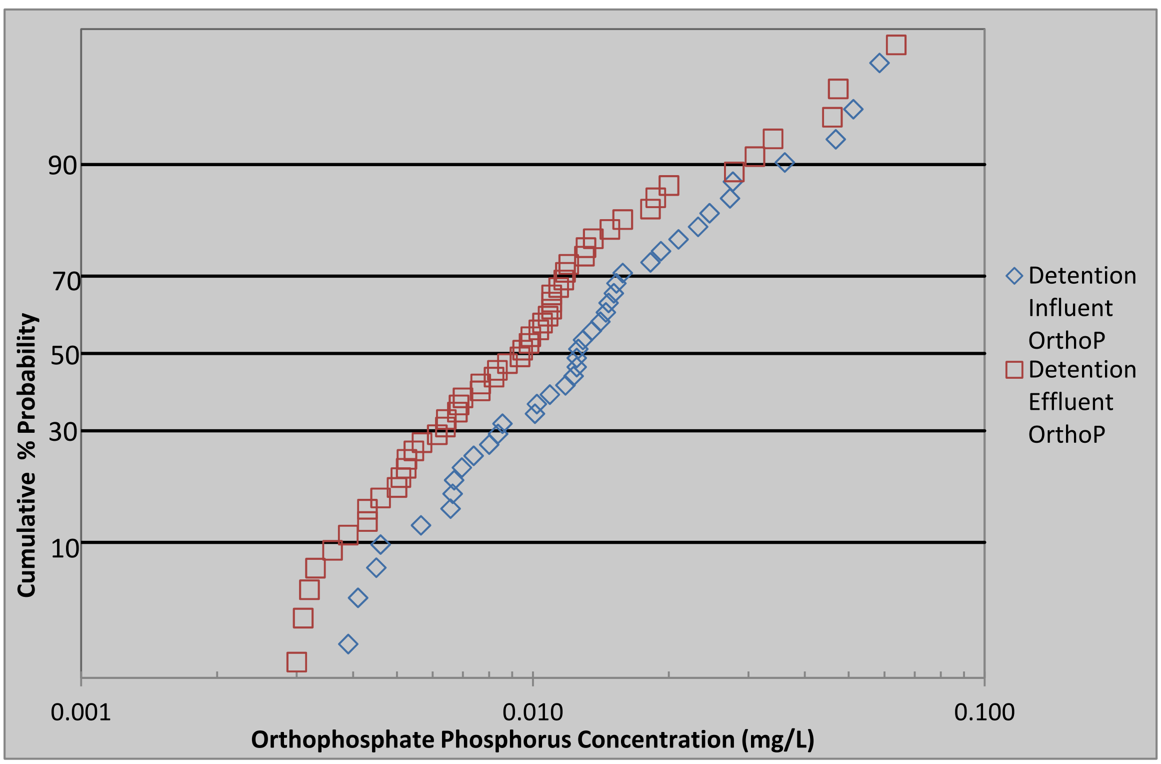

Figure 10. Probability plot for influent and effluent Orthophosphate Phosphorus concentrations collected at the Pre-Settling Detention Basin BMPs.

5.2.4 Total Copper

Based on the data collected from influent events at the detention sites, influent total copper concentrations ranged 0.00097 mg/L to 0.0421 mg/L, with a median value of 0.00408 mg/L (Table 24). Across the range of events sampled at the outlet of the BMP, effluent concentrations ranged from 0.00098 mg/L to 0.0118 mg/L, with a median value of 0.00217 mg/L. As shown in Table 20, mean total copper effluent concentrations are lower than influent concentrations, with a concentration based pollutant removal of 44 percent.

The total normalized total copper loads for the detention influent site was 0.0839 lbs. while the effluent total normalized load was 0.0357 lbs. The load based pollutant removal efficiency calculation showed a 57 percent reduction in total copper (Table 19).

A scatter plot of influent and effluent concentrations is presented in Figure 11. According to this scatter plot the influent and effluent concentrations appear to be similar. Cumulative percent probability plot (Figure 12) shows a slightly higher probability for lower effluent concentrations in the middle range of concentrations. At the higher and lower concentrations influent and effluent probabilities are similar. Results from a 1-tailed t-test that was applied to total copper data indicate the difference in effluent concentrations to influent concentration was statistically significant (p=0.012).

Table 24. Minimum, median, and maximum Total Copper concentrations from influent and effluent samples collected at the Pre-Settling Detention Basin BMPs.

	Influent Concentration (mg/L) (n=39)	Effluent Concentration (mg/L) (n=47)
Minimum	0.00097	0.00098
Median	0.00408	0.00217
Max	0.0421	0.0118

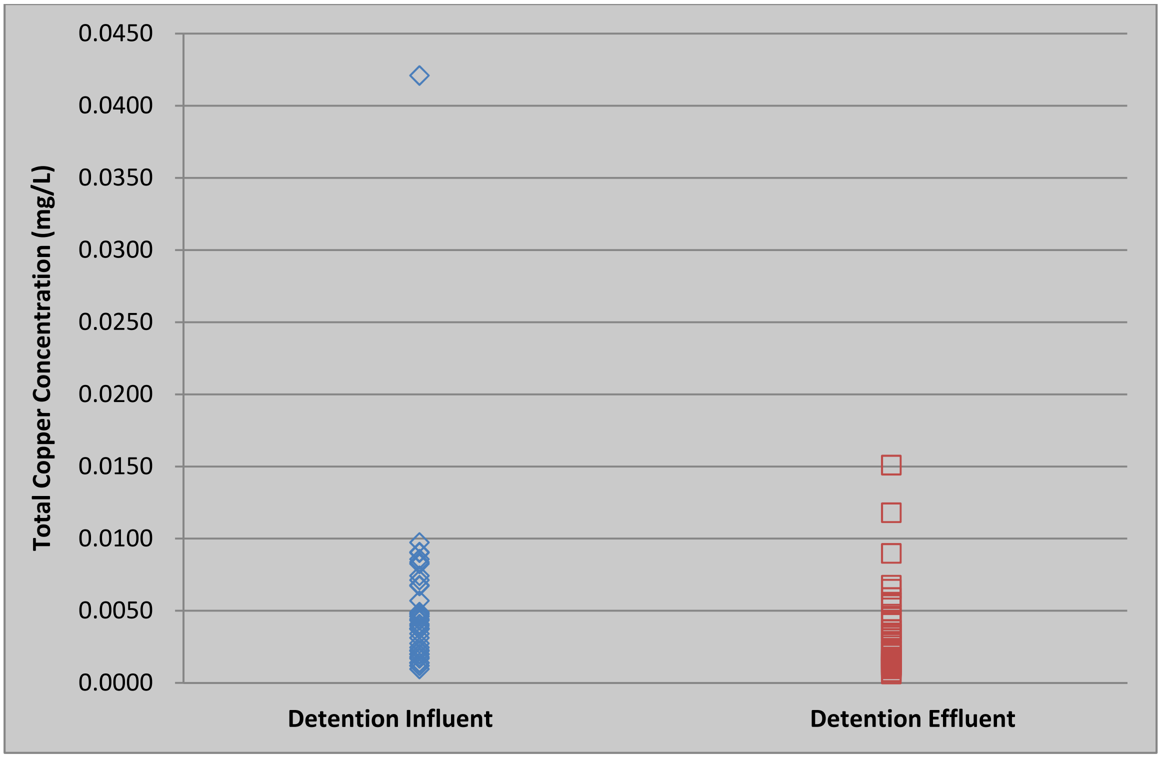

Figure 11. Scatter plot for influent and effluent Total Copper concentrations collected at the Pre-Settling Detention Basin BMPs.

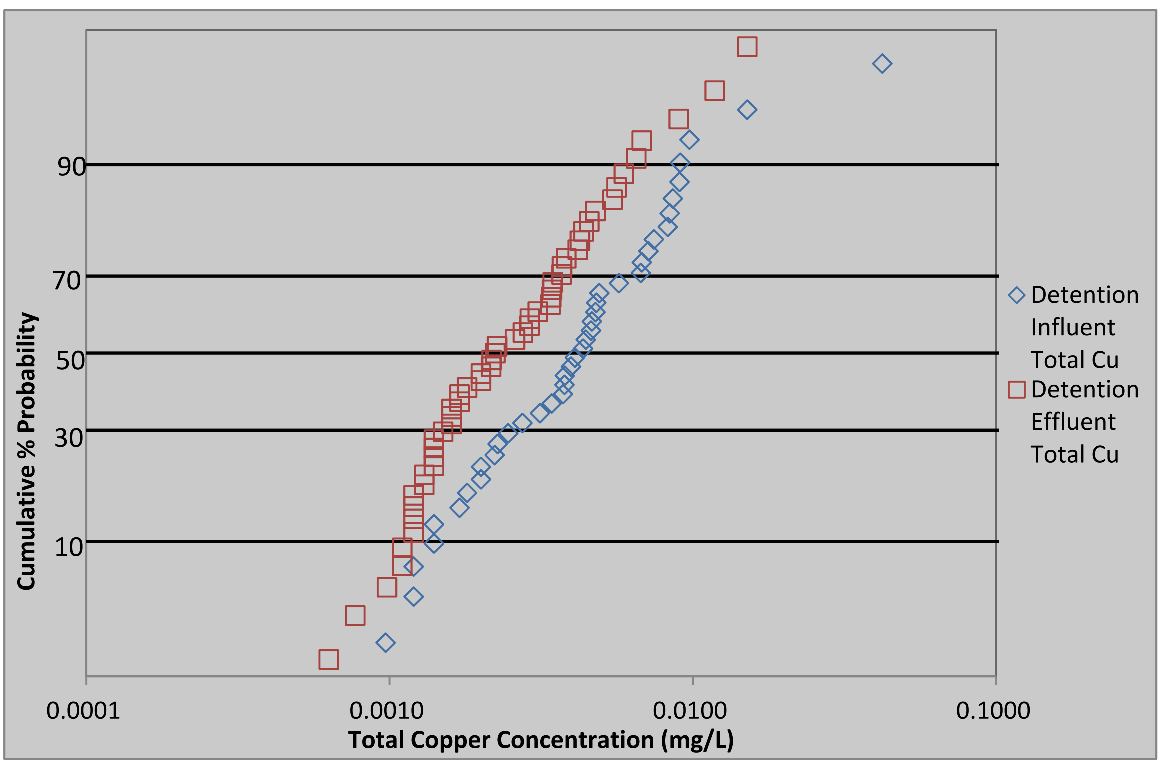

Figure 12. Probability plot for influent and effluent Total Copper concentrations collected at the Pre-Settling Detention Basin BMPs.

5.2.5 Dissolved Copper

Based on the data collected at the detention sites, influent dissolved copper concentrations ranged from 0.00048 mg/L to 0.00503 mg/L, with a median value of 0.00213 mg/L (Table 25). Across the range of events sampled at the outlet of the BMP, effluent concentrations ranged 0.00065 to 0.00361 mg/L, with a median value of 0.0013 mg/L. As shown in Table 20, mean dissolved copper effluent concentrations are lower than influent concentrations, with a concentration based pollutant removal of 29 percent.

The total normalized dissolved copper loads for the detention influent site was 0.0311 lbs. while the effluent total normalized load was 0.0229 lbs. The load based pollutant removal efficiency calculation showed a 27 percent reduction in dissolved copper (Table 19).

A scatter plot of influent and effluent concentrations is presented in Figure 13. Influent and effluent concentrations appear to be similar; however effluent concentrations are more clustered below 0.002 mg/L. Effluent concentrations were below the reporting detection limit for 73.5 percent of the samples. The cumulative percent probability is shown in Figure 14, and indicates a consistent probability of a lower effluent than influent concentrations across the range of concentrations. Results from a 1-tailed t-test that was applied to dissolved copper data confirmed the observed decrease in effluent concentrations to influent concentration was statistically significant (p=0.0069).

Table 25. Minimum, median, and maximum Dissolved Copper concentrations from influent and effluent samples collected at the Pre-Settling Detention Basin BMPs.

	Influent Concentration (mg/L) (n=39)	Effluent Concentration (mg/L) (n=45)
Minimum	0.00048	0.00065
Median	0.00213	0.0013
Max	0.00503	0.00361

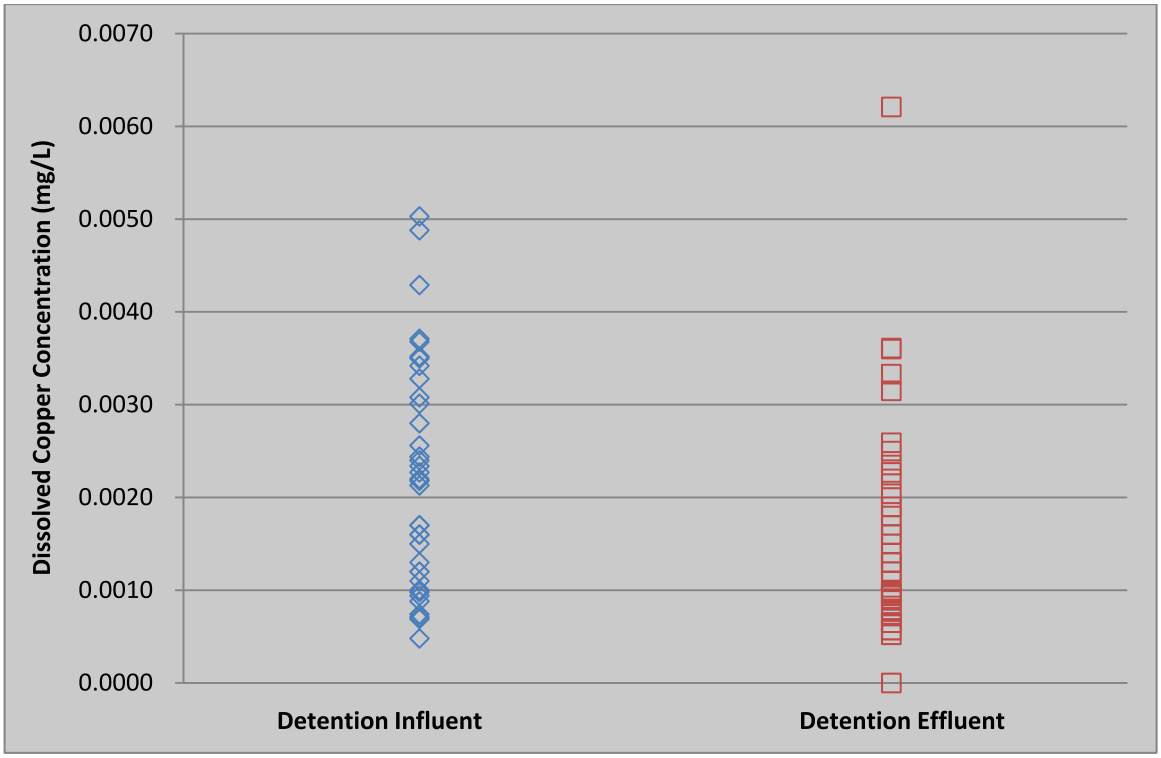

Figure 13. Scatter plot for influent and effluent Dissolved Copper concentrations collected at the Pre-Settling Detention Basin BMPs.

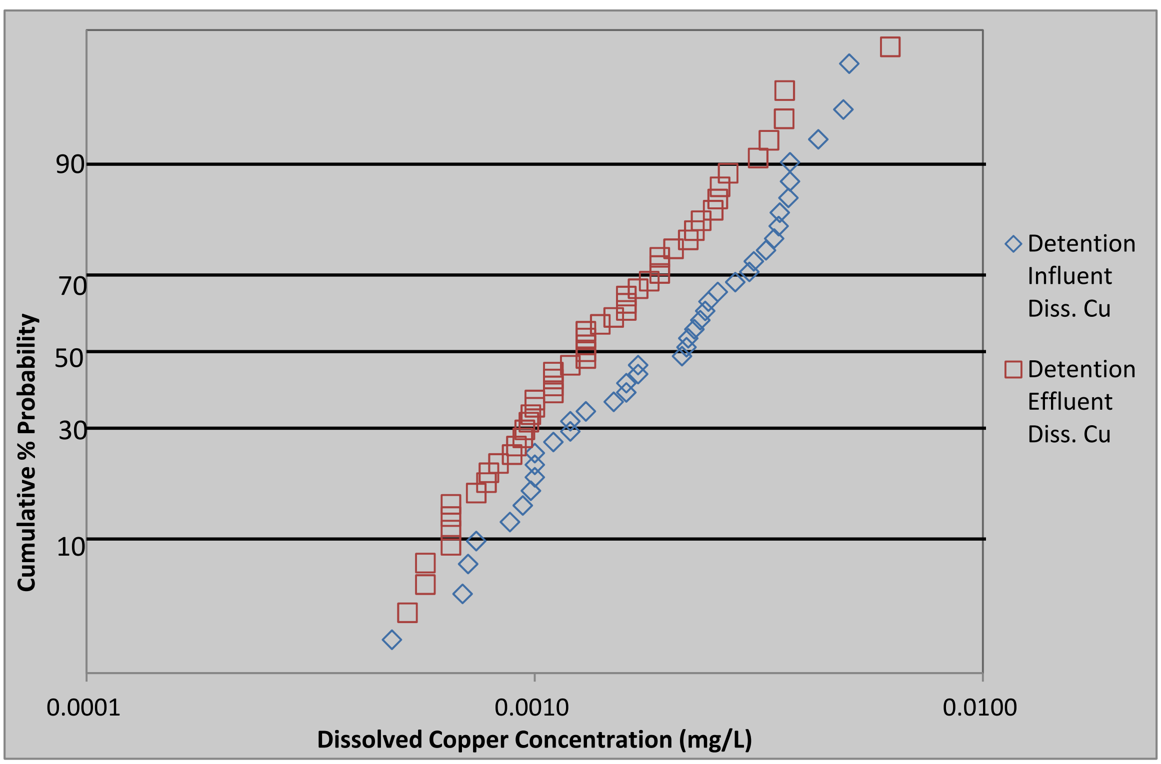

Figure 14. Probability plot for influent and effluent Dissolved Copper concentrations collected at the Pre-Settling Detention Basin BMPs.

5.2.6 Total Zinc

Based on the data collected from events at the detention sites, influent total zinc concentrations ranged from 0.00544 mg/L to 0.109 mg/L, with a median value of 0.01930 mg/L (Table 26). Across the range of events sampled at the outlet of the BMP, effluent concentrations ranged from 0.0015 mg/L to 0.0236 mg/L, with a median value of 0.00659 mg/L. As shown in Table 20, mean total zinc effluent concentrations are lower than mean influent concentrations, with a concentration based pollutant removal of 63 percent.

The total normalized total zinc loads for the detention influent site was 0.4306 lbs. while the effluent total normalized load was 0.1140 lbs. The load based pollutant removal efficiency calculation showed a 74 percent reduction in total zinc (Table 20).

A scatter plot of influent and effluent concentrations is presented in Figure 15. As shown on the graph, effluent concentrations were noticeably lower than influent concentrations. A cumulative percent probability plot (Figure 16), indicates a higher probabilities for lower effluent concentration are similar across the range of concentrations. Results from a 1-tailed Mann-Whitney test that was applied to the total zinc data confirmed the observed decrease in effluent concentrations to influent concentration was statistically significant ($p<0.0001$).

Table 26. Minimum, median, and maximum Total Zinc concentrations from influent and effluent samples collected at the Pre-Settling Detention Basin BMPs.

	Influent Concentration (mg/L) (n=39)	Effluent Concentration (mg/L) (n=50)
Minimum	0.00544	0.0015
Median	0.01930	0.00659
Max	0.109	0.0236

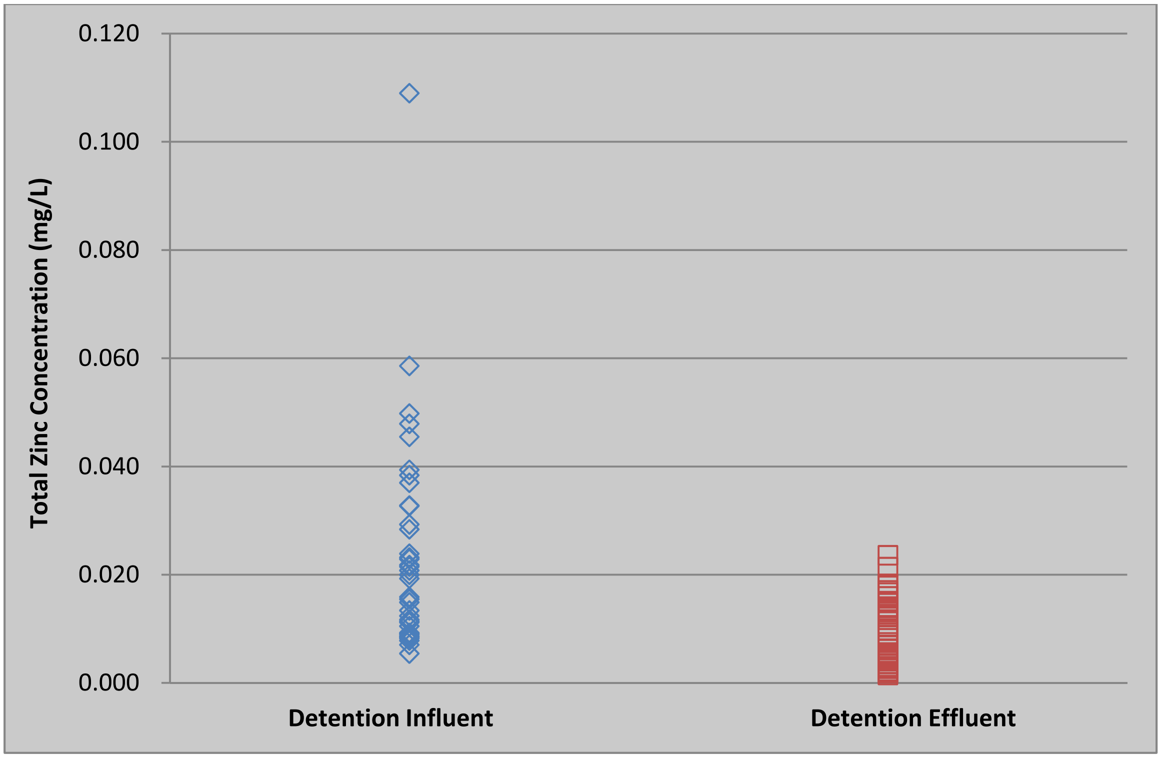

Figure 15. Scatter plot for influent and effluent Total Zinc concentrations collected at the Pre-Settling Detention Basin BMPs.

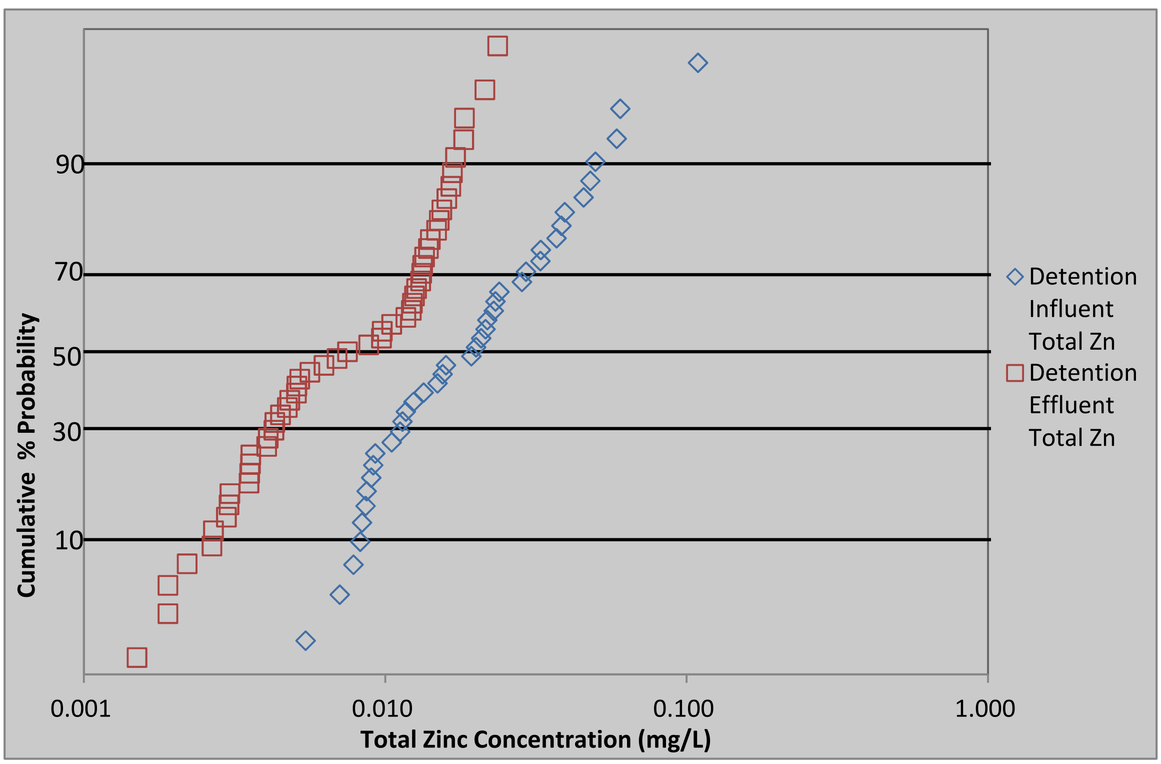

Figure 16. Probability plot for influent and effluent Total Zinc concentrations collected at the Pre-Settling Detention Basin BMPs.

5.2.7 Dissolved Zinc

Based on the data collected at the detention sites, influent dissolved zinc concentrations ranged from 0.00383 mg/L to 0.022 mg/L, with a median value of 0.00708 mg/L (Table 27). Across the range of events sampled at the outlet of the BMP, effluent concentrations ranged from 0.00087 mg/L to 0.01370 mg/L, with a median value of 0.00376 mg/L. As shown in Table 20, mean dissolved zinc effluent concentrations are lower than mean influent concentrations, with a concentration based pollutant removal of 33 percent.

The total normalized dissolved zinc loads for the detention influent site was 0.1382 lbs. while the effluent total normalized load was 0.0722 lbs. The load based pollutant removal efficiency calculation showed a 44 percent reduction in dissolved zinc (Table 19).

A scatter plot of influent and effluent concentrations shows that influent concentrations were generally higher than effluent concentrations (Figure 17). The cumulative percent probability plot (Figure 18), shows a similar probability for the influent and effluent at the higher concentrations, with higher probability of lower effluent at lower to middle concentrations. Results from a 1-tailed Mann-Whitney test that was applied to dissolved zinc data indicate the decrease in effluent concentrations to influent concentration was statistically significant (p=0.0003).

Table 27. Minimum, median, and maximum Dissolved Zinc concentrations and loads from influent and effluent samples collected at the Pre-Settling Detention Basin BMPs.

	Influent Concentration (mg/L) (n=39)	Effluent Concentration (mg/L) (n=50)
Minimum	0.00383	0.00087
Median	0.00708	0.00376
Max	0.022	0.01370

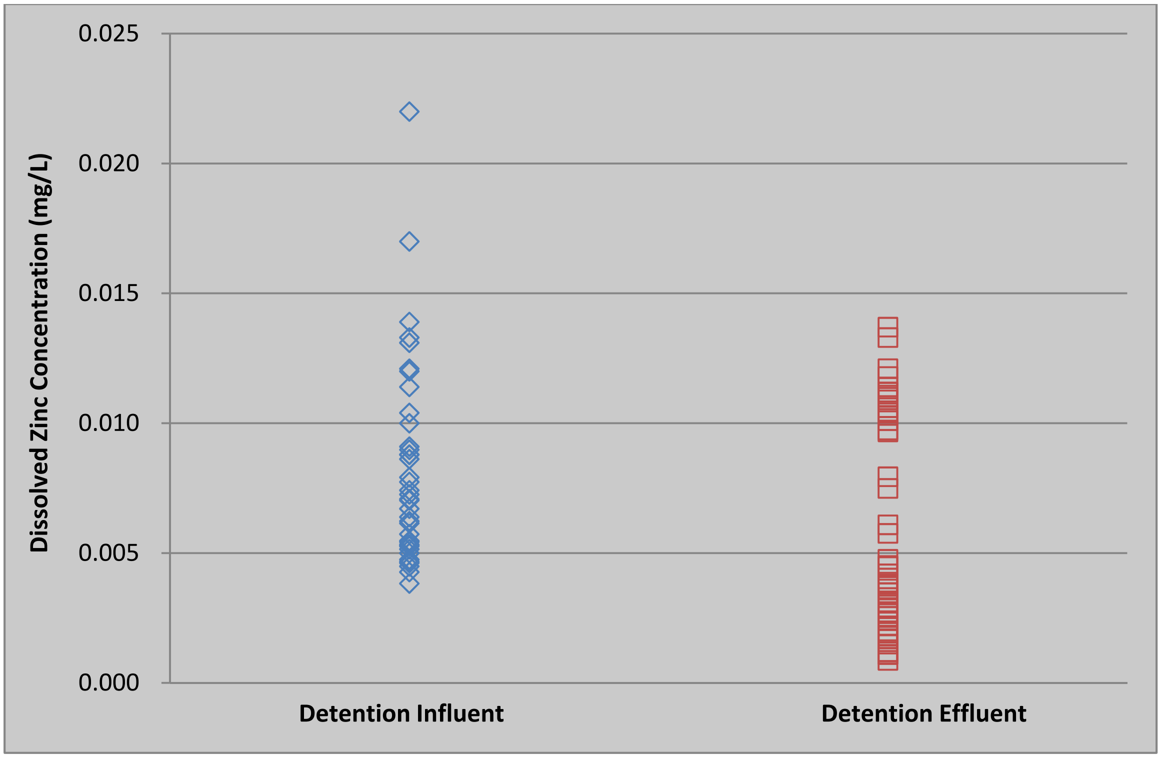

Figure 17. Scatter plot for influent and effluent Dissolved Zinc concentrations collected at the Pre-Settling Detention Basin BMPs.

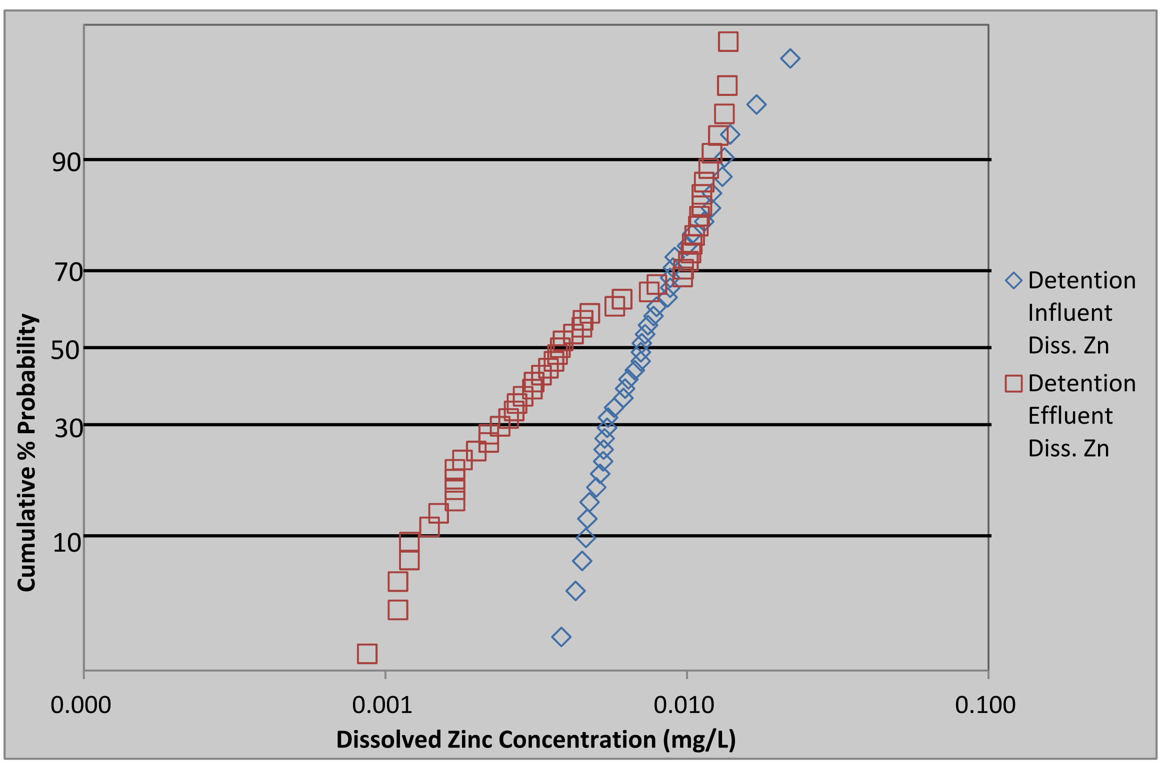

Figure 18. Probability plot for influent and effluent Dissolved Zinc concentrations collected at the Pre-Settling Detention Basin BMPs.

5.3 Large Sand Filter BMP

There were a total of 53 influent and 43 effluent samples collected at the large sand filter BMPs. Twenty of the influent sample events and eleven of the effluent sample events met the TAPE guidelines as outlined in Section 3.1. There were no outliers removed from the datasets, however during two influent sample events equipment errors caused a loss of flow data. As a result, data from these events were not included in the load based pollutant removal efficiency calculations.

Summary statistics for the load based pollutant removal efficiencies and the concentration based pollutant removal efficiencies are presented in Table 28 and Table 29, respectively. Load based pollutant removals ranged from 88.9 percent reduction in TSS to a -77.9 percent reduction in dissolved copper. More details about each parameter are provided in the following sections. Concentration based pollutant removals ranged from a 91 percent reduction in TSS to a -46 percent reduction in dissolved copper.

Table 28. Summary of load based pollutant removal efficiencies for the Large Sand Filters

Parameter	Normalized Inlet Load (lbs)	Normalized Detention Outlet Load (lbs)	Percent Reduction
TSS	176.29	19.48	88.9%
Total Phosphorus	1.6226	0.6278	61.3%
OrthoPhosphate Phosphorus	0.4137	0.2670	35.5%
Total Copper	0.0518	0.0659	-27.1%
Dissolved Copper	0.0343	0.0611	-77.9%
Total Zinc	0.1617	0.0479	70.4%
Dissolved Zinc	0.1096	0.0453	58.7%

Table 29. Summary of concentration based pollutant removal efficiencies for the Large Sand Filters

Parameter	Influent				Effluent				Percent Reduction	Statistically Significant at α=0.10[1] (Y/N)	Statistical Power
	Mean Concentration (mg/L)	COV (%)	95% Confidence Interval (mg/L)		Mean Concentration (mg/L)	COV (%)	95% Confidence Interval (mg/L)				
TSS	8.98922	157	3.99523	6.53702	0.81488	87	0.47755	0.76128	91%	Y	99.4%
Total Phosphorus	0.06579	96	0.04033	0.05986	0.02271	77	0.01458	0.02427	65%	Y	94.0%
OrthoPhosphate Phosphorus	0.01179	96	0.00753	0.01096	0.01005	73	0.00737	0.01055	15%	N	13.4%
Total Copper	0.00316	89	0.00200	0.00394	0.00257	80	0.00184	0.00258	19%	N	29.0%
Dissolved Copper	0.00154	69	0.00113	0.00221	0.00224	65	0.00166	0.00224	-46%	Y	80.3%
Total Zinc	0.00877	67	0.00586	0.01024	0.00265	89	0.00175	0.00271	70%	Y	100.0%
Dissolved Zinc	0.00552	74	0.00349	0.00646	0.00234	87	0.00155	0.00230	58%	Y	99.9%

[1]As suggested in TAPE Appendix D, for all parameters except TSS statistical significance was evaluated at an α=0.10. For TSS statistical significance was evaluated at an α=0.05.

5.3.1 Total Suspended Solids

Based on the data collected at the sand filter sites, influent TSS concentrations ranged from 1.6 mg/L to 85.7 mg/L, with a median value of 4.4 mg/L (Table 30). Across the range of events sampled at the outlet of the BMP, effluent concentrations ranged from a non-detect (less than 0.5 mg/L) to 2.73 mg/L, with a median value of 0.5 mg/L. As shown in Table 29, mean TSS effluent concentrations are lower than mean influent concentrations, with a concentration based pollutant removal of 91 percent. Greater than 39 percent of the effluent samples were below the method detection limit, and 72 percent of the effluent samples were below the reporting limit so the pollutant removal of 91 percent should be considered an estimate.

The total normalized TSS loads for the sand filter influent site was 176.29 lbs. while the effluent total normalized load was 19.48 lbs. The load based pollutant removal efficiency calculation showed an 88.9 percent reduction in TSS (Table 28).

A scatter plot of influent and effluent concentrations shows consistently low effluent concentrations for a range of influent concentrations (Figure 19). In addition, the cumulative percent probability plot shown in Figure 20 shows a consistently higher probability for lower effluent concentrations. Results from a 1-tailed Mann-Whitney[2] test that was applied to TSS data confirmed the observed decrease in effluent concentrations to influent concentration was statistically significant ($p<0.0001$).

Table 30. Minimum, median, and maximum TSS concentrations from influent and effluent samples collected at the Large Sand Filter BMPs.

	Influent Concentration (mg/L) (n=51)	Effluent Concentration (mg/L) (n=43)
Minimum	1.6	<0.5
Median	4.4	0.5
Max	85.7	2.73

[2] All influent and effluent Sand Filter datasets were deemed as having a non-normal distribution, therefore a Mann-Whitney test was used to test for statistical significance.

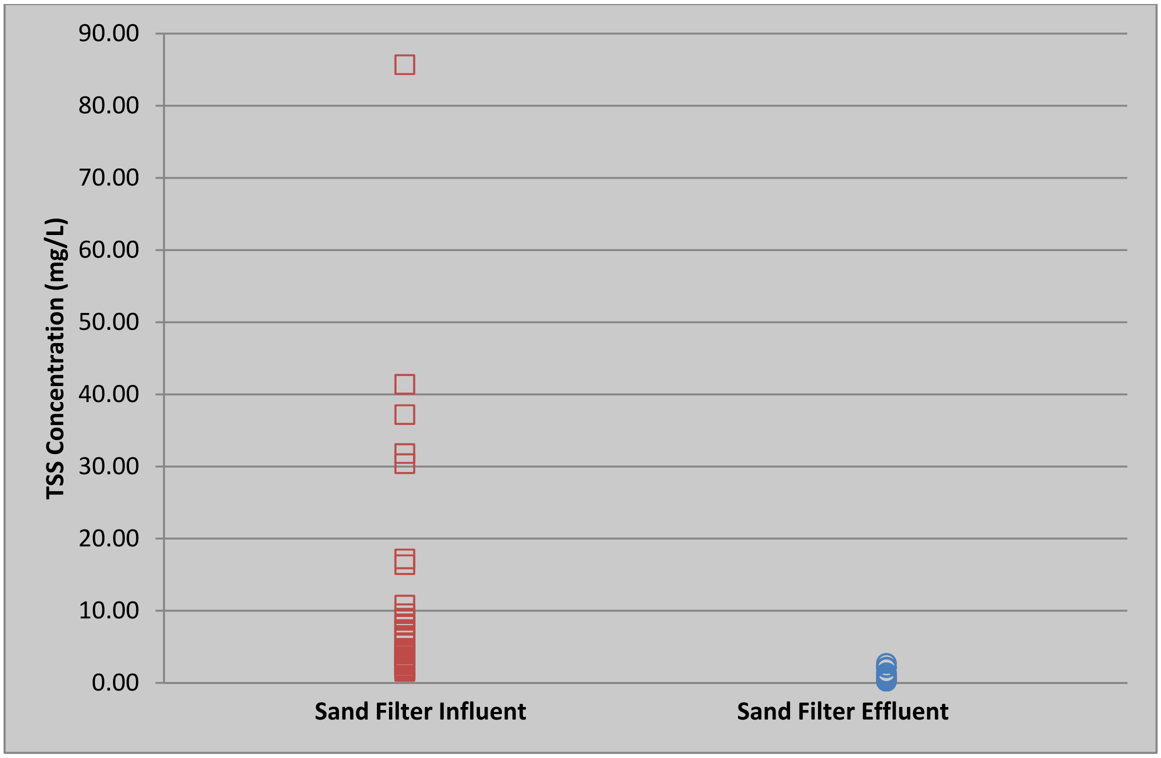

Figure 19. Scatter plot for influent and effluent TSS concentrations collected at the Large Sand Filter BMPs.

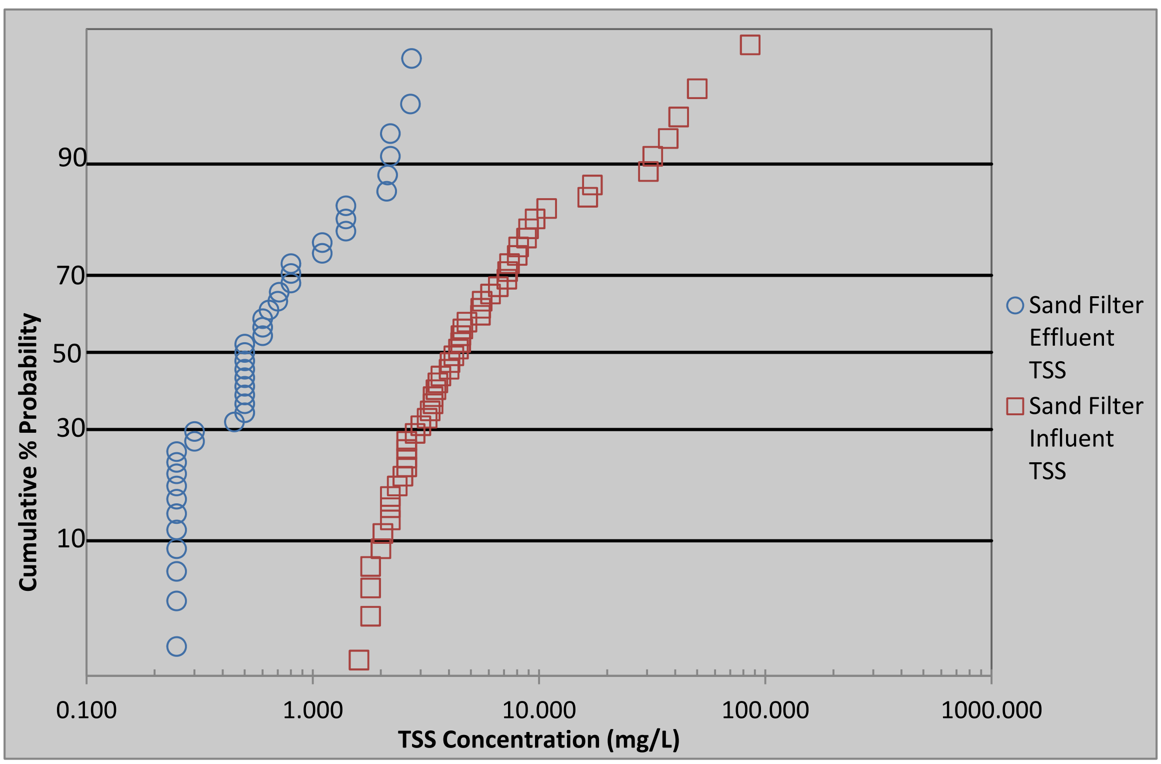

Figure 20. Probability plot for influent and effluent TSS concentrations collected at the Large Sand Filter BMPs.

5.3.2 Total Phosphorus

Based on the data collected at the sand filter sites, influent total phosphorus concentrations ranged from 0.0148 mg/L to 0.383 mg/L, with a median value of 0.0459 mg/L (Table 31). Across the range of events sampled at the outlet of the BMP, effluent concentrations ranged from a non-detect (less than 0.005 mg/L) to 0.0753 mg/L, with a median value of 0.0176 mg/L. As shown in Table 29, mean total phosphorus effluent concentrations are lower than mean influent concentrations, with a concentration based pollutant removal of 65 percent.

The total normalized total phosphorus loads for the sand filter influent site was 1.6226 lbs. while the effluent total normalized load was 0.6278 lbs. The load based pollutant removal efficiency calculation showed a 61.3 percent reduction in total phosphorus (Table 28).

A scatter plot of influent and effluent concentrations is presented in Figure 21 shows lower effluent than influent concentrations across a range of influent concentrations. The cumulative percent probability plot shown in Figure 22 also shows a consistently higher probability of lower effluent concentrations across the range of concentrations. Results from a 1-tailed Mann-Whitney test that was applied to total phosphorus data confirmed the observed decrease in effluent concentrations to influent concentration was statistically significant ($p<0.0001$).

Table 31. Minimum, median, and maximum Total Phosphorus concentrations from influent and effluent samples collected at the Large Sand Filter BMPs.

	Influent Concentration (mg/L) (n=51)	Effluent Concentration (mg/L) (n=43)
Minimum	0.0148	<0.005
Median	0.0459	0.0176
Max	0.383	0.0753

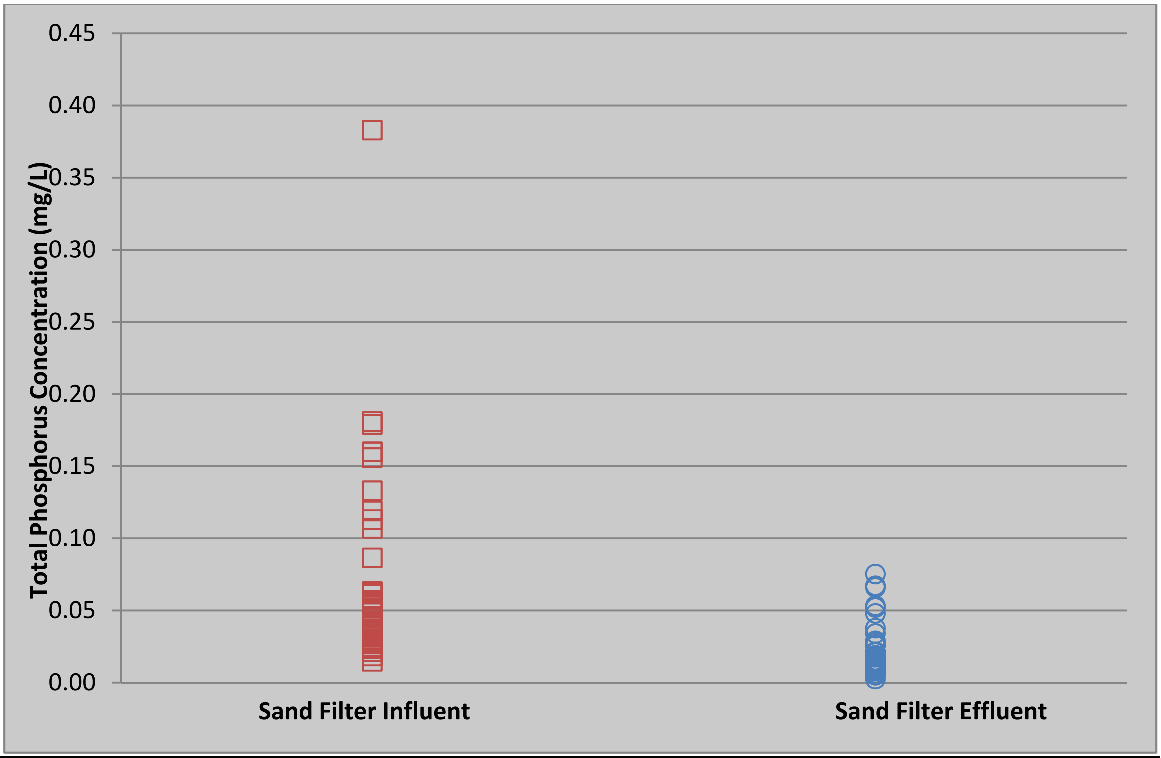

Figure 21. Scatter plot for influent and effluent Total Phosphorus concentrations collected at the Large Sand Filter BMPs.

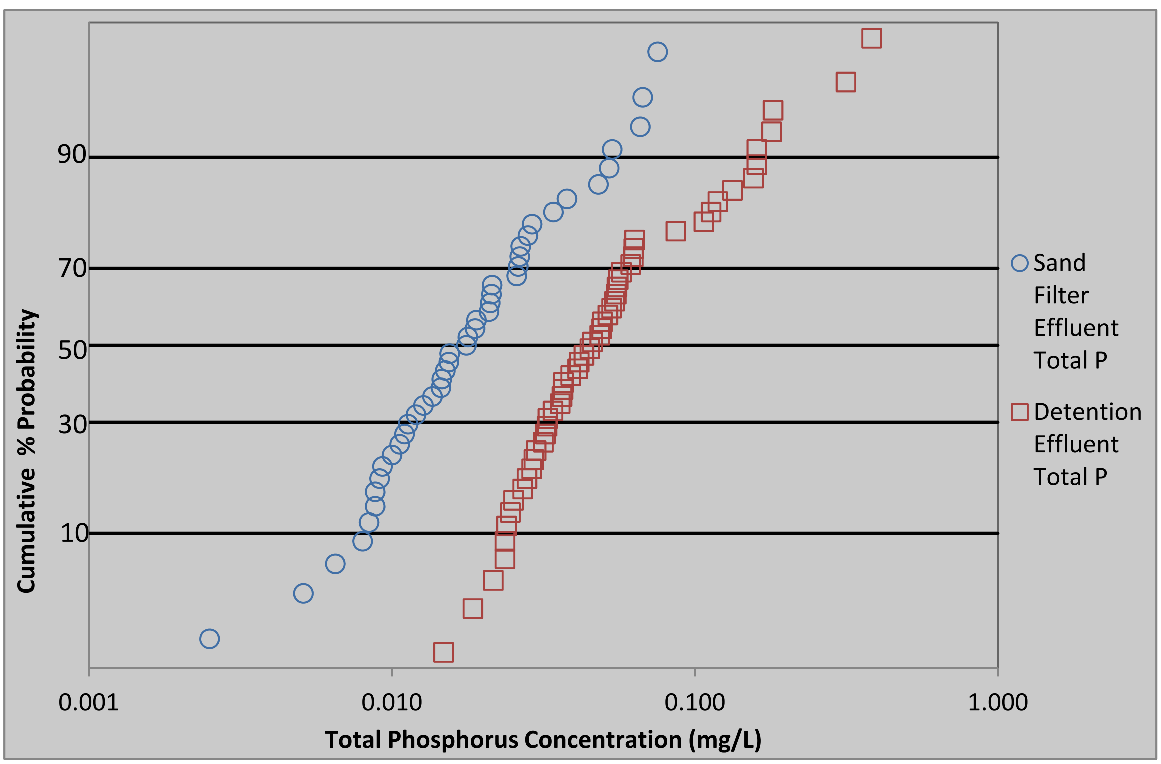

Figure 22. Probability plot for influent and effluent Total Phosphorus concentrations collected at the Large Sand Filter BMPs.

5.3.3 Orthophosphate Phosphorus

Based on the data collected at the sand filter sites, influent orthophosphate phosphorus concentrations ranged from a no-detect (<0.006 mg/L) to 0.0637 mg/L, with a median value of 0.00878 mg/L (Table 32). Across the range events sampled at the outlet of the BMP, effluent concentrations ranged from 0.0035 mg/L to 0.0355 mg/L, with a median value of 0.00729 mg/L. As shown in Table 29, the concentration based percent reduction for orthophosphate phosphorus is 15 percent.

The total normalized orthophosphate phosphorus loads for the sand filter influent site was 0.4137 lbs. while the effluent total normalized load was 0.0267 lbs. The load based pollutant removal efficiency calculation showed a 35.5 percent reduction in orthophosphate phosphorus (Table 28).

A scatter plot of influent and effluent concentrations, presented in Figure 23, generally shows similar concentrations in influent and effluent orthophosphate phosphorus concentrations. The probability plot for orthophosphate phosphorus (Figure 24) indicates that the probabilities were similar across the range of the influent and effluent concentrations. Results from a 1-tailed Mann-Whitney test that was applied to orthophosphate phosphorus data confirmed that the difference in the influent and effluent concentrations were not statistically significant ($p=0.3299$).

Table 32. Minimum, median, and maximum Orthophosphate Phosphorus concentrations from influent and effluent samples collected at the Large Sand Filter BMPs.

	Influent Concentration (mg/L) (n=51)	Effluent Concentration (mg/L) (n=43)
Minimum	<0.006	0.0035
Median	0.00878	0.00729
Max	0.0637	0.0355

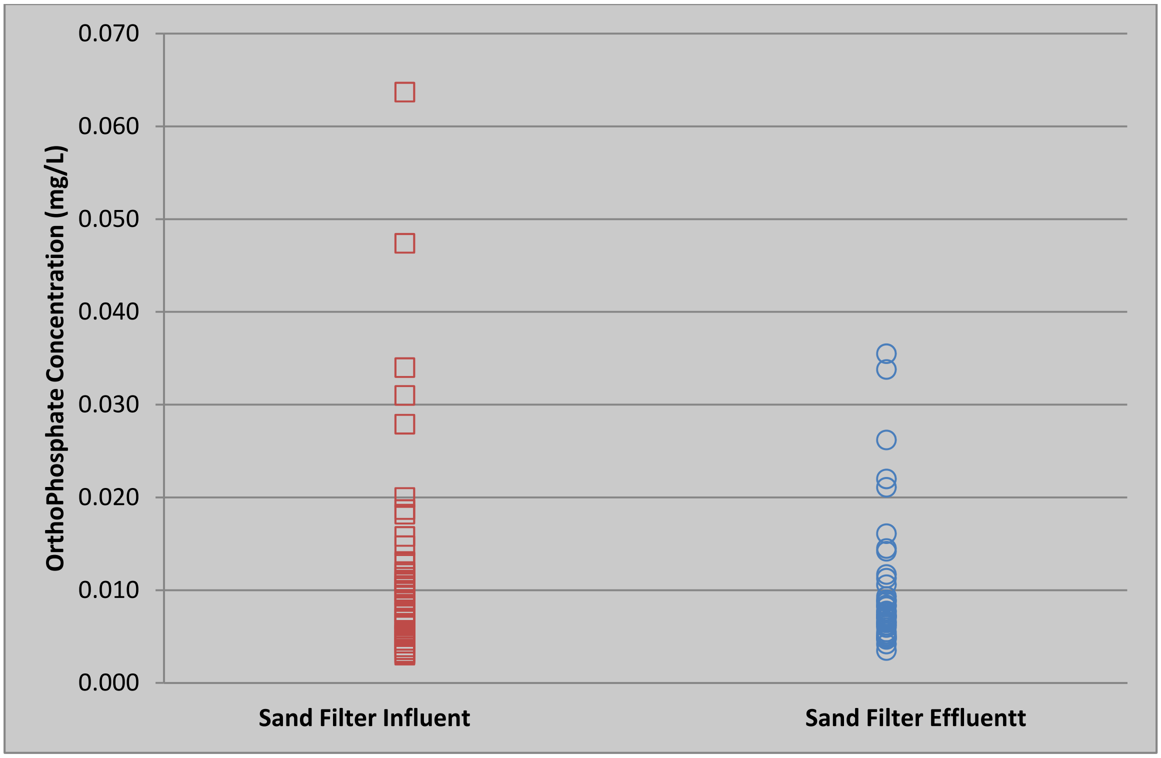

Figure 23. Scatter plot for influent and effluent Orthophosphate Phosphorus concentrations collected at the Large Sand Filter BMPs.

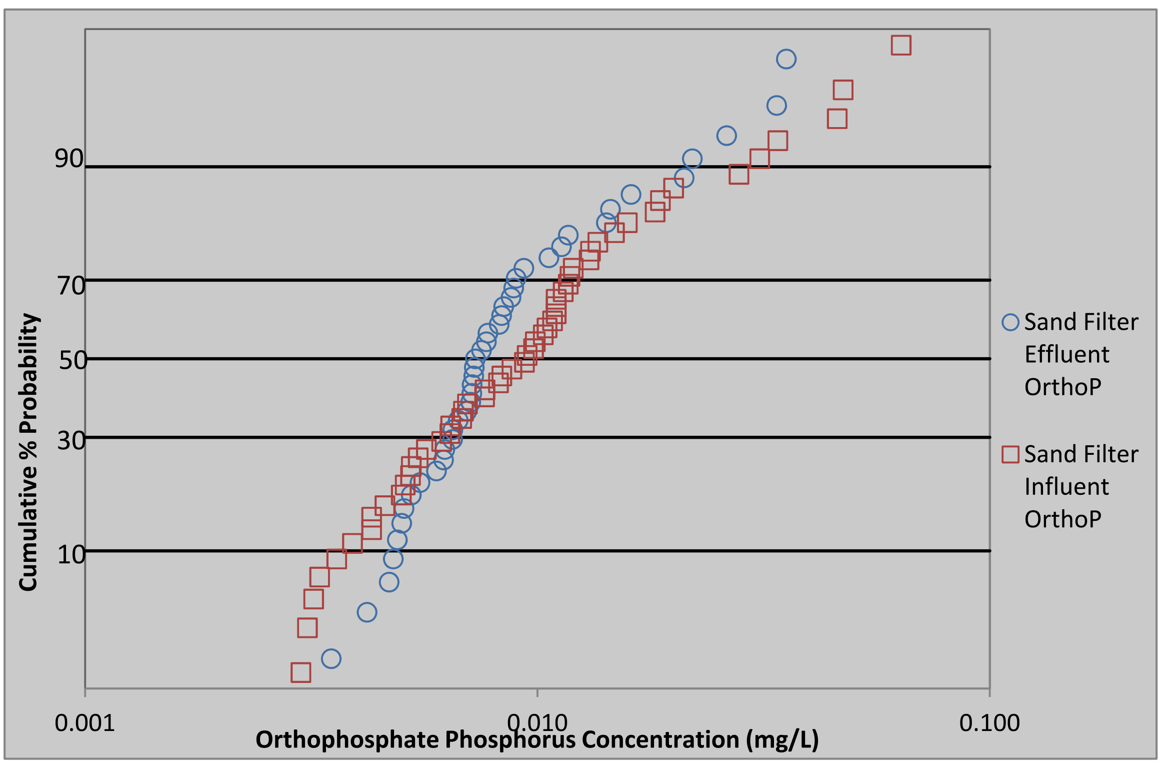

Figure 24. Probability plot for influent and effluent Orthophosphate Phosphorus concentrations collected at the Large Sand Filter BMPs.

5.3.4 Total Copper

Based on the data collected from sampling events at the sand filter sites, influent total copper concentrations ranged from 0.00063 mg/L to 0.01510 mg/L, with a median value of 0.00217 mg/L (Table 33). Across the range of events sampled at the outlet of the BMP, effluent concentrations ranged from 0.001 mg/L to 0.0117 mg/L, with a median value of 0.00195 mg/L. As shown in Table 29, the concentration based percent reduction for total copper is 19 percent.

The total normalized total copper loads for the sand filter influent site was 0.0518 lbs. while the effluent total normalized load was 0.0659 lbs. The load based pollutant removal efficiency calculation showed a -27.1 percent reduction in total copper (Table 28).

A scatter plot of influent and effluent concentrations, presented in Figure 25, generally showed lower effluent concentrations as compared to influent concentrations. The probability plot for total copper (Figure 26) indicates the cumulative probabilities for influent and effluent concentration are similar across the range of concentrations. Results from a 1-tailed Mann-Whitney test that was applied to orthophosphate phosphorus data confirmed that the difference in the influent and effluent concentrations were not statistically significant (p=0.2716).

Table 33. Minimum, median, and maximum Total Copper concentrations from influent and effluent samples collected at the Large Sand Filter BMPs.

	Influent Concentration (mg/L) (n=50)	Effluent Concentration (mg/L) (n=42)
Minimum	0.00063	0.001
Median	0.00217	0.00195
Max	0.01510	0.0117

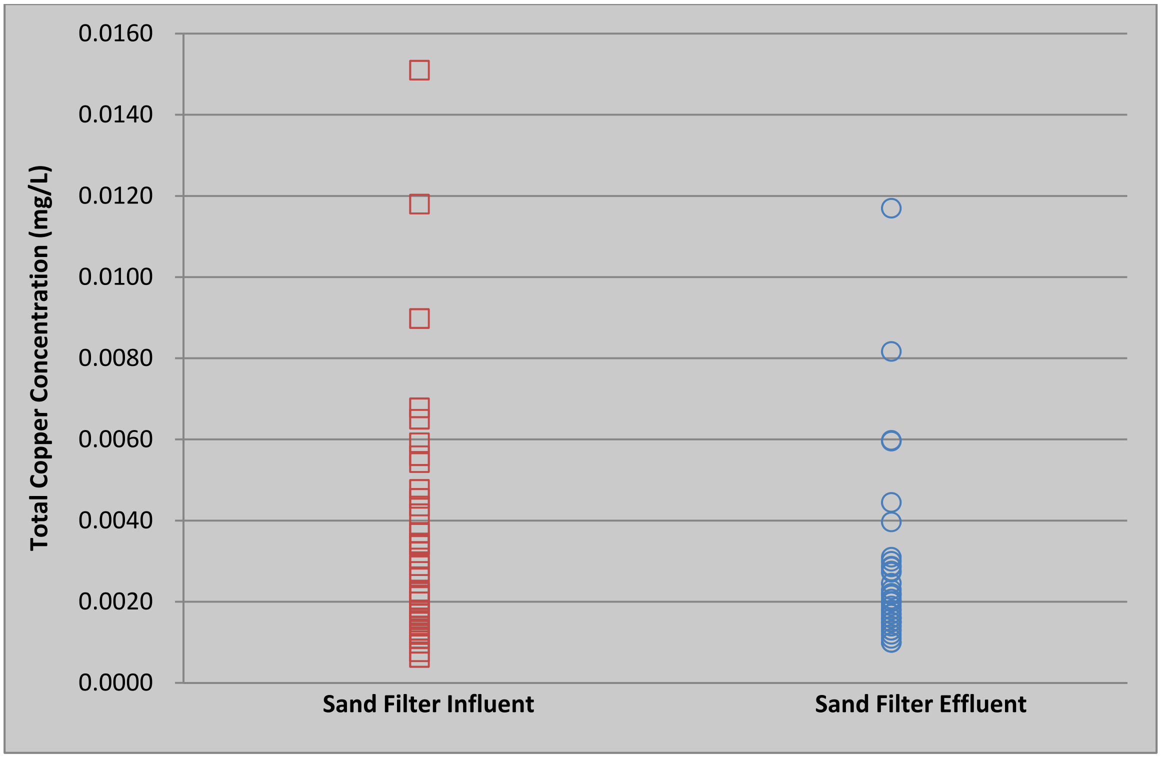

Figure 25. Scatter plot for influent and effluent Total Copper concentrations collected at the Large Sand Filter BMPs.

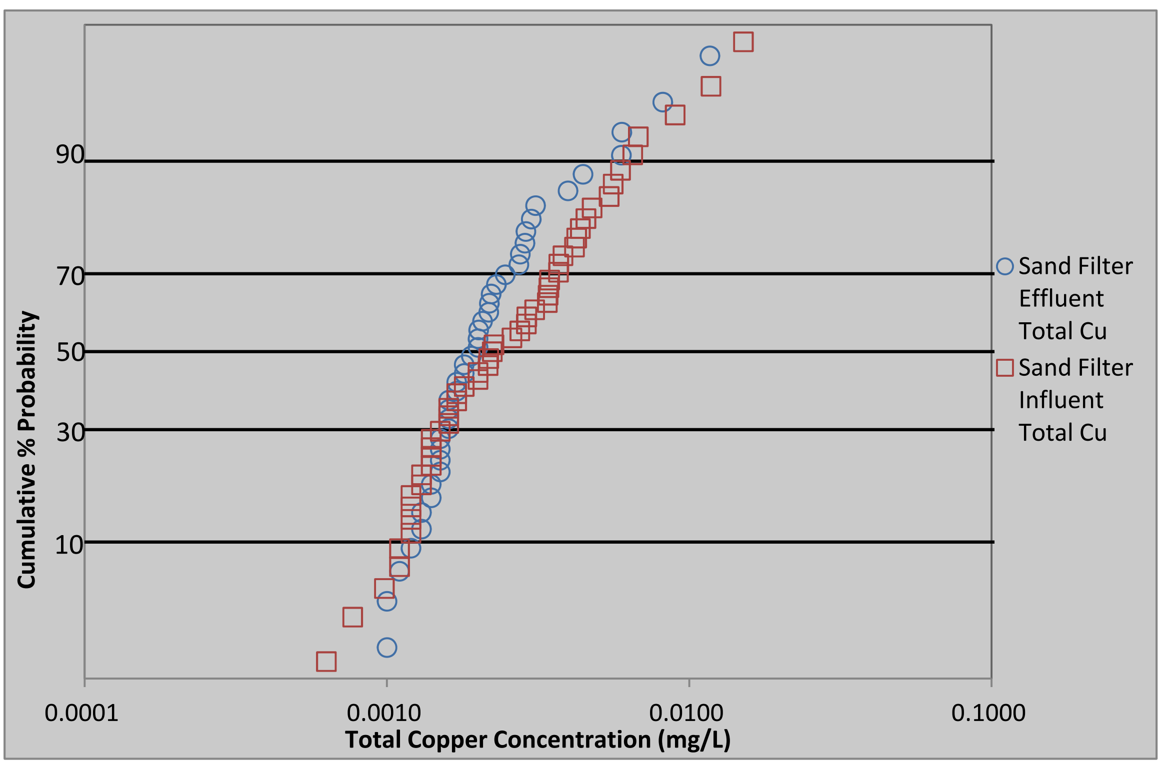

Figure 26. Probability plot for influent and effluent Total Copper concentrations collected at the Large Sand Filter BMPs.

5.3.5 Dissolved Copper

Based on the data collected from events at the sand filter site, influent dissolved copper concentrations ranged from a non-detect (less than 0.0004 mg/L) to 0.00621 mg/L, with a median value of 0.0013 mg/L (Table 34). Across the range of events sampled at the outlet of the BMP, effluent concentrations ranged 0.001 mg/L to 0.00782 mg/L, with a median value of 0.0017 mg/L. As shown in Table 29, the mean effluent concentration for dissolved copper was higher than the mean influent concentration, resulting in a negative percent reduction (-46 percent).

The total normalized dissolved copper loads for the sand filter influent site was 0.0343 lbs. while the effluent total normalized load was 0.0611 lbs. Similar to the concentration based pollutant removal efficiency, the load based pollutant removal calculation showed a negative percent reduction of -77.9 percent (Table 28).

A scatter plot of influent and effluent concentrations (Figure 27) generally shows similar concentrations, with effluent concentrations being slightly higher. As shown in Table 28, the probability plot for dissolved copper (Figure 28) indicates there is a higher probability that effluent concentrations are greater than influent concentrations across the range of concentrations. Results from a 1-tailed Mann-Whitney test that was applied to dissolved copper data confirmed that the difference in the influent and effluent concentrations was statistically significant (p=0.0003).

Table 34. Minimum, median, and maximum Dissolved Copper concentrations from influent and effluent samples collected at the Large Sand Filter BMPs.

	Influent Concentration (mg/L) (n=50)	Effluent Concentration (mg/L) (n=42)
Minimum	<0.0004	0.001
Median	0.0013	0.0017
Max	0.00621	0.00782

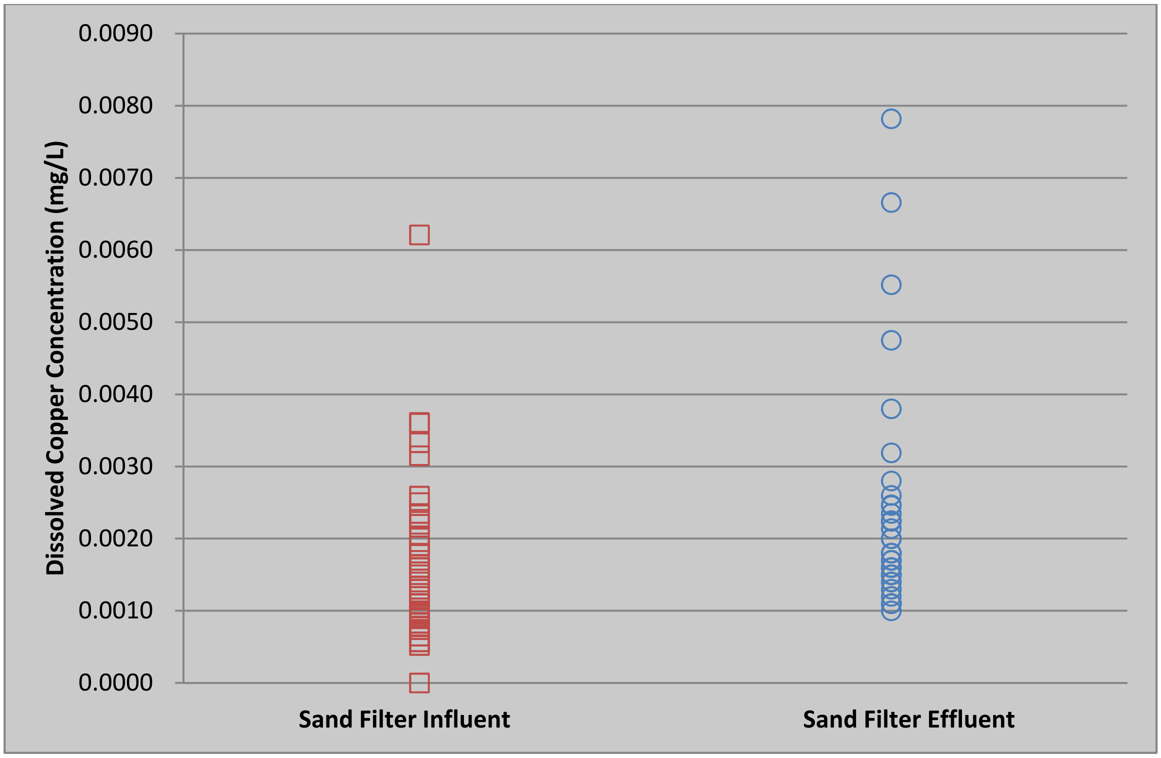

Figure 27. Scatter plot for influent and effluent Dissolved Copper concentrations collected at the Large Sand Filter BMPs.

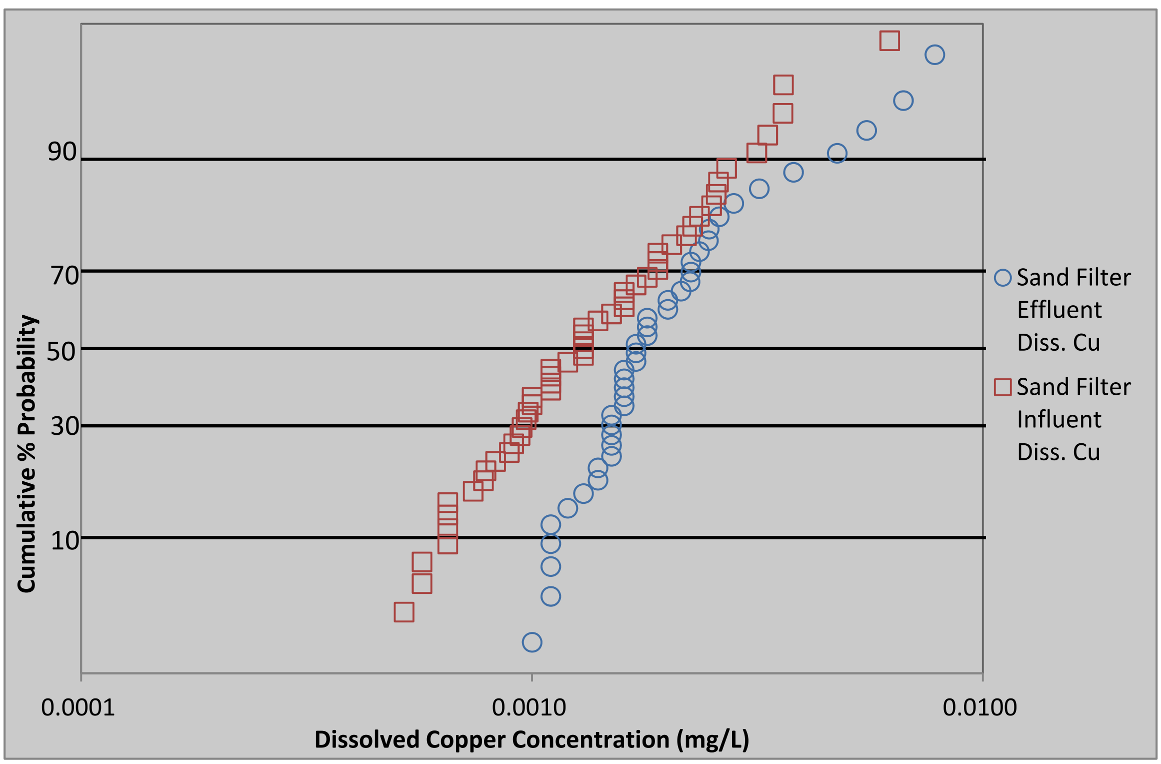

Figure 28. Probability plot for influent and effluent Dissolved Copper concentrations collected at the Large Sand Filter BMPs.

5.3.6 Total Zinc

Based on the data collected at the sand filter sites, influent total zinc concentrations ranged from 0.0015 mg/L to 0.0236 mg/L, with a median value of 0.00659 mg/L (Table 35). Across the range of events sampled at the outlet of the BMP, effluent concentrations ranged from 0.00072 mg/L to 0.0116 mg/L, with a median value of 0.002 mg/L. As shown in Table 29, mean total zinc effluent concentrations are lower than influent concentrations, with a concentration based pollutant removal of 70 percent.

The total normalized total zinc loads for the sand filter influent site was 0.1617 lbs. while the effluent total normalized load was 0.0479 lbs. The load based pollutant removal efficiency calculation showed a 70.4 percent reduction in total zinc (Table 28).

A scatter plot of influent and effluent concentrations, presented in Figure 29, shows lower effluent concentrations of total zinc across a range of influent concentrations. The cumulative percent probability plot (Figure 30) indicates a higher probability of lower effluent concentration across the range of concentrations. Results from a 1-tailed Mann-Whitney test that was applied to total zinc data confirmed the observed decrease in effluent concentrations to influent concentration was statistically significant ($p<0.0001$).

Table 35. Minimum, median, and maximum Total Zinc concentrations from influent and effluent samples collected at the Large Sand Filter BMPs.

	Influent Concentration (mg/L) (n=50)	Effluent Concentration (mg/L) (n=42)
Minimum	0.0015	0.00072
Median	0.00659	0.002
Max	0.0236	0.0116

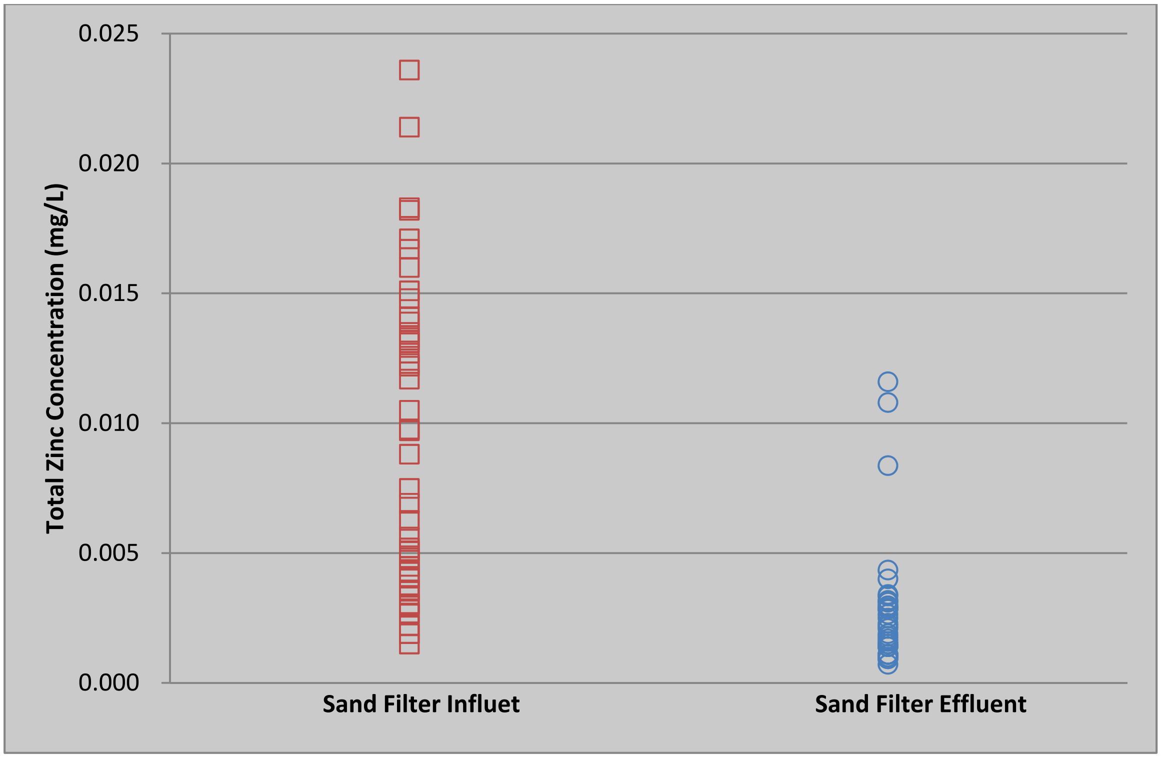

Figure 29. Scatter plot for influent and effluent Total Zinc concentrations collected at the Large Sand Filter BMPs.

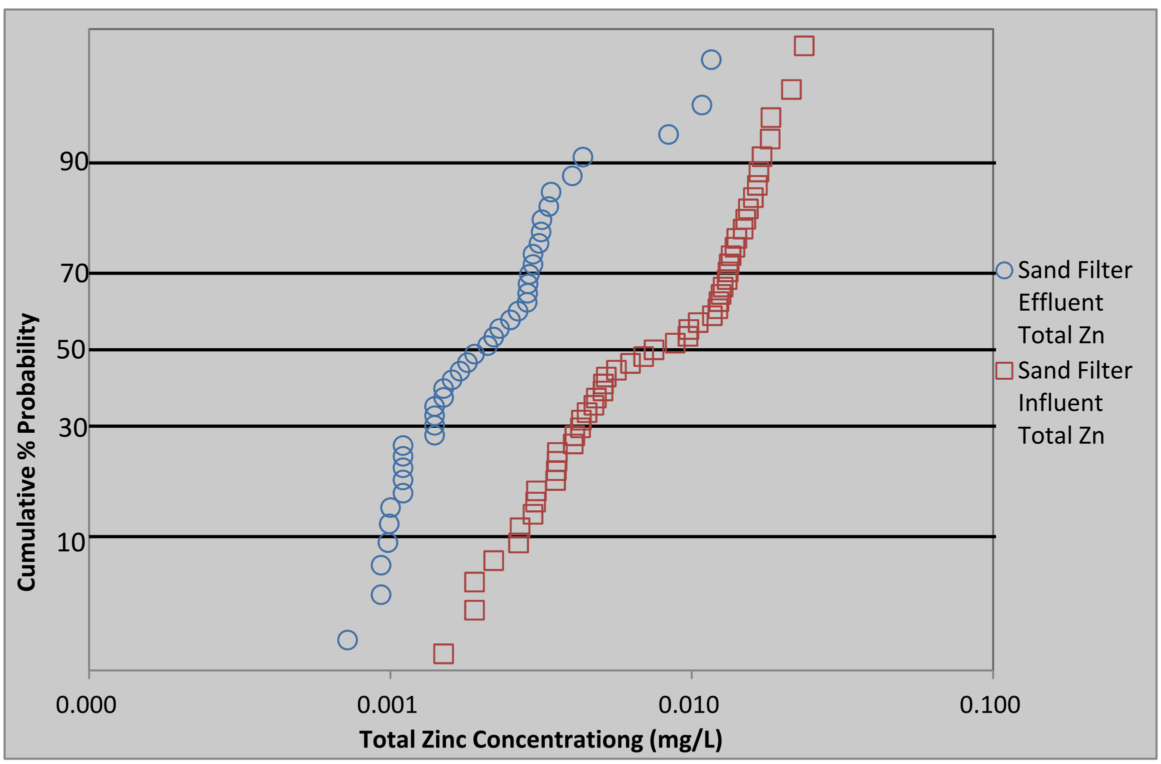

Figure 30. Probability plot for influent and effluent Total Zinc concentrations collected at the Large Sand Filter BMPs.

5.3.7 Dissolved Zinc

Based on the data collected from sample events at the sand filter sites, influent dissolved zinc concentrations ranged from 0.00087 mg/L to 0.0137 mg/L, with a median value of 0.00376 mg/L (Table 36). Across the range of the 43 events sampled at the outlet of the BMP, effluent concentrations ranged from a non-detect (less than 0.005 mg/L) to 0.0104 mg/L, with a median value of 0.0016 mg/L. As shown in Table 29, mean dissolved zinc effluent concentrations are lower than mean influent concentrations, with a concentration based pollutant removal of 58 percent.

The total normalized dissolved zinc loads for the sand filter influent site was 0.1096 lbs. while the effluent total normalized load was 0.0453 lbs. The load based pollutant removal efficiency calculation showed a 58.7 percent reduction in dissolved zinc (Table 28).

A scatter plot of dissolved zinc influent and effluent concentrations (Figure 31) shows lower influent concentrations across a range of effluent concentrations. The cumulative percent probability plot presented in Figure 32 generally indicates a greater probability for lower effluent concentrations, except at the high and low concentrations. At the very high and low concentrations influent and effluent probabilities are similar across the range of concentrations. Results from a 1-tailed Mann-Whitney test that was applied to dissolved zinc data confirmed the observed decrease in effluent concentrations to influent concentration was statistically significant ($p<0.0001$).

Table 36. Minimum, median, and maximum Dissolved Zinc concentrations from influent and effluent samples collected at the Large Sand Filter BMPs.

	Influent Concentration (mg/L) (n=50)	Effluent Concentration (mg/L) (n=42)
Minimum	0.00087	<0.0005
Median	0.00376	0.0016
Max	0.0137	0.0104

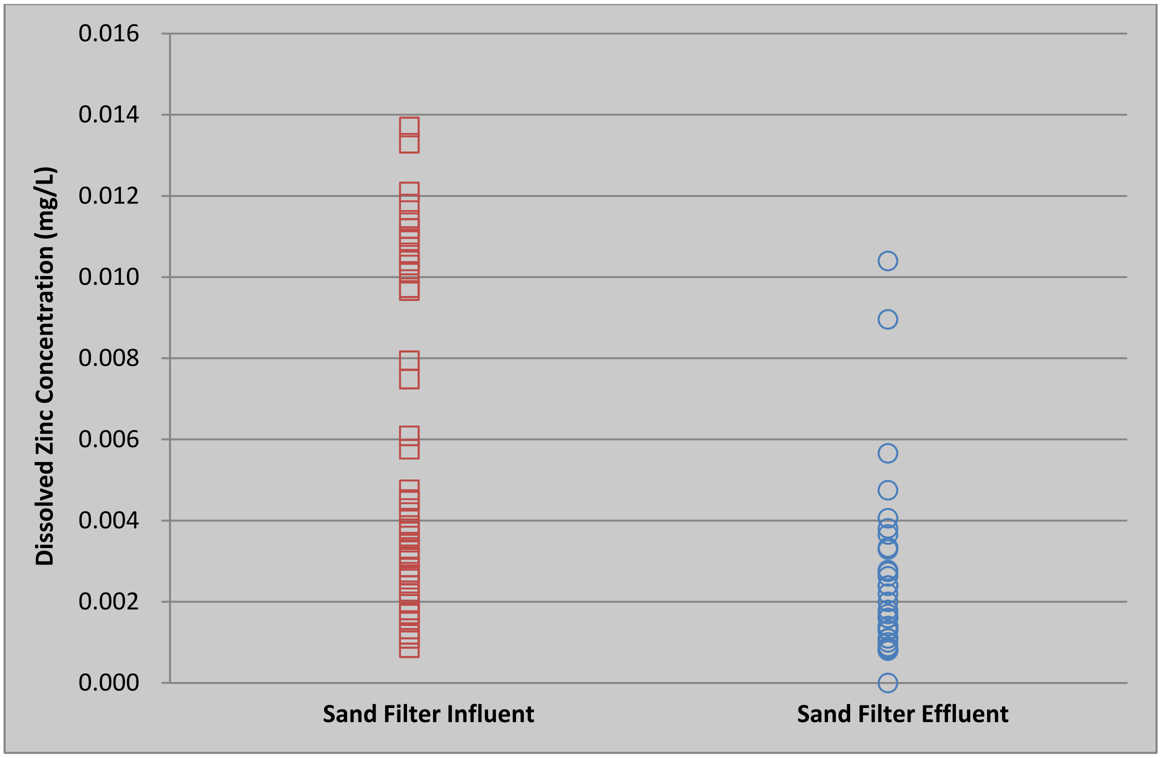

Figure 31. Scatter plot for influent and effluent Dissolved Zinc concentrations collected at the Large Sand Filter BMPs.

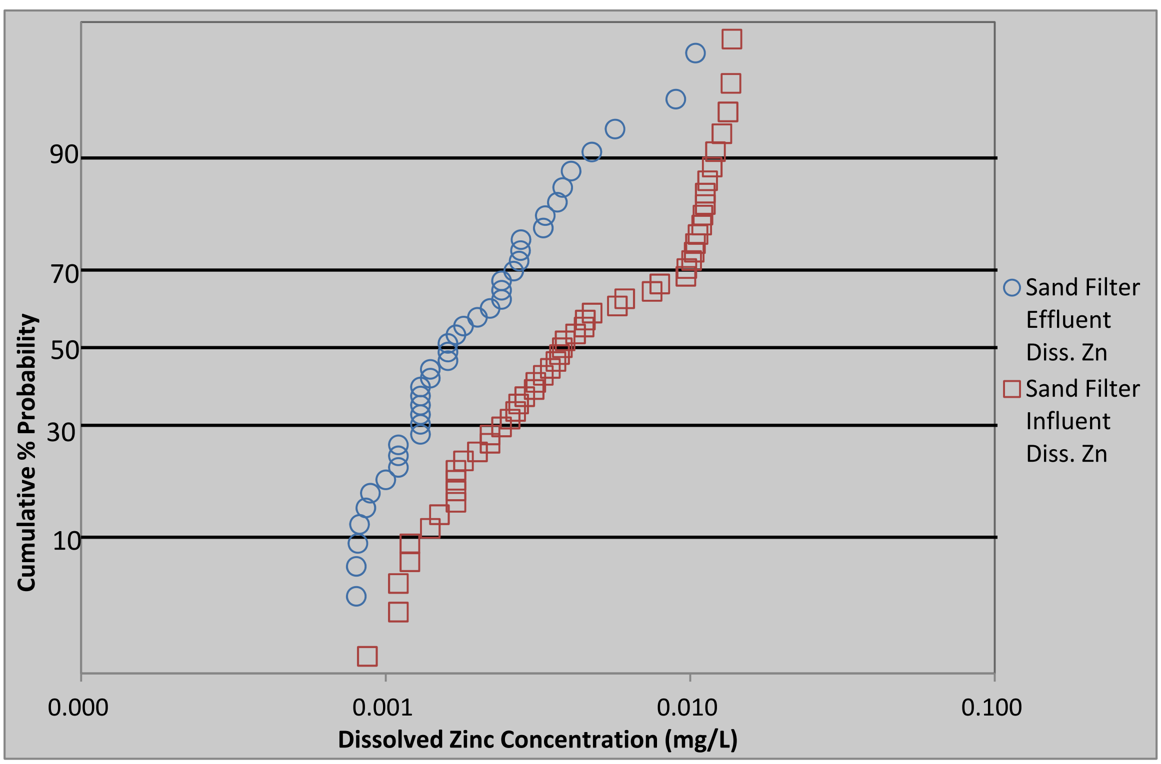

Figure 32. Probability plot for influent and effluent Dissolved Zinc concentrations collected at the Large Sand Filter BMPs.

5.4 Discussions

The pre-settling detention basin BMP (Detention Pond and Detention Vault) is designed for Basic runoff treatment objectives, while the large sand filter BMP is designed for Basic, Phosphorus, and Enhanced treatment objectives. A general discussion of how well each BMP performed relative to the Basic, Enhanced, and Phosphorus treatment goals is provided below.

5.4.1 Basic Treatment Goals

Based on TAPE guidelines (Ecology, 2008a), the treatment performance goals for basic treatment is 80 percent removal for TSS concentrations where influent concentrations fall between 100 to 200 mg/L. For influent concentrations less than 100 mg/L, the effluent goal is less than 20 mg/L.

For the pre-settling detention basin, influent TSS concentrations ranged from less than 0.095 mg/L to 72.3 mg/L, with a mean concentration of 17.23 mg/L and a median influent concentration of 13.8 mg/L. Concentration based pollutant removal efficiency for TSS was 48 percent. All influent concentrations were less than 100 mg/L. While the Boulder Creek Pre-Settling Detention Basins do meet the TAPE treatment performance goals with a mean effluent concentration of 8.99 mg/L and a median effluent concentration of 4.2 mg/L, the mean influent concentration was already below the effluent TSS goal of 20 mg/L.

For the large sand filter, influent TSS concentrations ranged from 1.6 mg/L to 85.7 mg/L, with a mean concentration of 8.99 mg/L and a median influent concentration of 4.4 mg/L. As with the pre-settling detention basin, all influent concentrations were less than 100 mg/L Concentration based pollutant removal efficiency was 91 percent. Again, the Boulder Creek large sand filter results do meet the TAPE goals with a mean effluent concentration of 0.81 mg/L and a median effluent concentration of 0.5 mg/L. However, the mean influent concentration was already well below the effluent TSS goal of 20 mg/L. In addition, 72 percent of the TSS effluent concentrations were below the reporting limit, and therefore the 91 percent removal efficiency should be considered an estimate.

5.4.2 Phosphorus Treatment Goals

TAPE guidelines set a goal for phosphorus treatment at 50 percent removal for influent total phosphorus concentrations between 0.1 mg/L and 0.5 mg/L. For influent concentrations greater than 0.5 mg/L a higher percent removal goal may be appropriate.

For the pre-settling detention basin BMP, influent total phosphorus concentrations ranged from 0.0186 mg/L to 0.244 mg/L, with 82.5 percent of influent samples falling below the concentration range stated in TAPE. The mean influent concentration was 0.0572 mg/L while the mean effluent concentration was 0.06579. This resulted in a concentration based pollutant removal efficiency of -15 percent. These results do not appear to meet the TAPE treatment performance goals, however the detention pond and detention vault BMPs are not designed for phosphorus removal.

For the large sand filter BMP, the influent total phosphorus concentrations ranged from 0.0148 mg/L to 0.383 mg/L, with 75 percent of influent samples falling below the concentration range needed to conform to TAPE. The mean influent concentration was 0.066 mg/L while the mean effluent concentration was 0.023. This resulted in a concentration based pollutant removal efficiency for total phosphorus of 65 percent. This does meet the TAPE treatment performance goals, however due to the low influent concentrations it is uncertain if these data would meet the TAPE goals.

5.4.3 Enhanced Treatment Goals

Enhanced treatment goals for TAPE state data collected for an enhanced BMP should demonstrate significantly higher removal rates for dissolved metals than basic treatment BMPs. In addition to the removal goals, TAPE criteria states influent dissolved copper concentrations must be in the range of 0.003 to 0.02 mg/L (3 to 20 µg/L) and influent dissolved zinc concentrations must be in the range 0.02 to 0.3 mg/L (20 to 300 µg/L).

For the pre-settling detention basin BMP, influent dissolved copper concentrations ranged from 0.00048 mg/L to 0.00503 mg/L, with 70 percent of the 40 samples falling below the influent concentration range required by TAPE. The mean influent dissolved copper concentration was 0.00215 mg/L and the mean effluent concentration was 0.00153 mg/L, resulting in concentration based pollutant removal efficiency for dissolved copper of 29 percent. Influent dissolved zinc concentrations ranged from 0.00383 mg/L to 0.022 mg/L, with 97.5 percent of the 40 samples falling below the influent concentration range required by TAPE. The mean effluent dissolved zinc concentration was 0.00552, resulting in a 33 percent reduction in dissolved zinc. Due to the low influent concentrations it is unlikely these data would meet the TAPE goals, however the detention pond and detention vault BMPs are not designed for enhanced treatment.

For the large sand filter BMP, 89 percent of the 53 samples fell below the influent dissolved copper concentration range required by TAPE. The mean influent dissolved copper concentration was 0.00154 mg/L and the mean effluent concentration 0.00224 mg/L, resulting in a -46 percent reduction in dissolved copper. For dissolved zinc samples, 98.2 percent of the concentrations fell below the range required by TAPE. The mean influent dissolved zinc concentration was 0.00552 mg/L and the mean effluent concentration was 0.00234 mg/L, resulting in a 58 percent reduction in dissolved zinc. As with the detention basin BMP, due to the low influent concentrations it is unlikely these data would meet the TAPE goals.

6.0. REFERENCES

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